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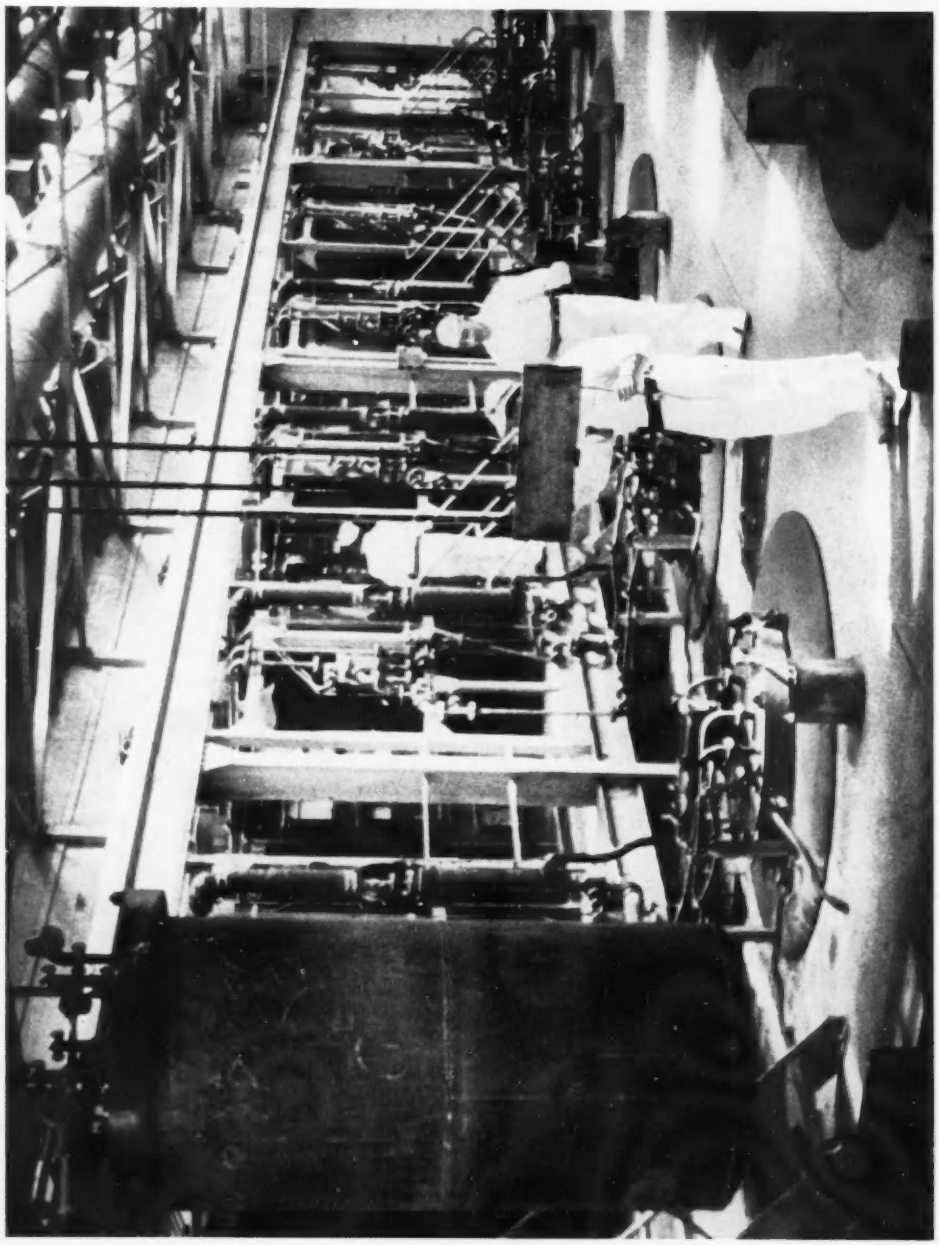

EQUIPMENT FOR ATOMIC FACTORIES.

Some of the fifty-four furnaces supplied by the G.E.C. for the production of uranium metal.

The First Coal-washing Plant in India at West Bokaro

By D. M. SMITH, M.I.E.E., M.M.G.I., and H. G. HAGUE, M.Inst.F.
Fraser & Chalmers Engineering Works.

SITE DETAILS.

WEST Bokaro, the site of the first coal-washing plant in India, lies to the West of the Bihar Coalfields some 20 miles from Hazaribagh (literal interpretation: 1,000 gardens or 1,000 tigers) and 275 miles by road to the north-west from Calcutta (fig. 1). Judging by the paucity of gardens and the prevalence of jungle, tigers and other wild game, it is safe to presume that in this case the literal meaning of Hazaribagh is land of a thousand tigers.

The coal mining rights had been leased by the Rajah of Ramgarh to Anderson Wright & Co., of Calcutta, who in turn formed the holding company of Bokaro & Ramgur, Ltd. This concern over a long period of years surveyed the field, generally under difficult conditions of terrain, and were instrumental in sub-leasing some of the more accessible areas for coal production; the coal was, however, chiefly utilised for purposes other than metallurgical coke making. This was due to the high ash and phosphorus contents of the coal, rendering it unsuitable for steel making. The Tata Iron & Steel Co., Ltd., became interested in 1939, and it is due to the courage of this concern that pioneering development was undertaken

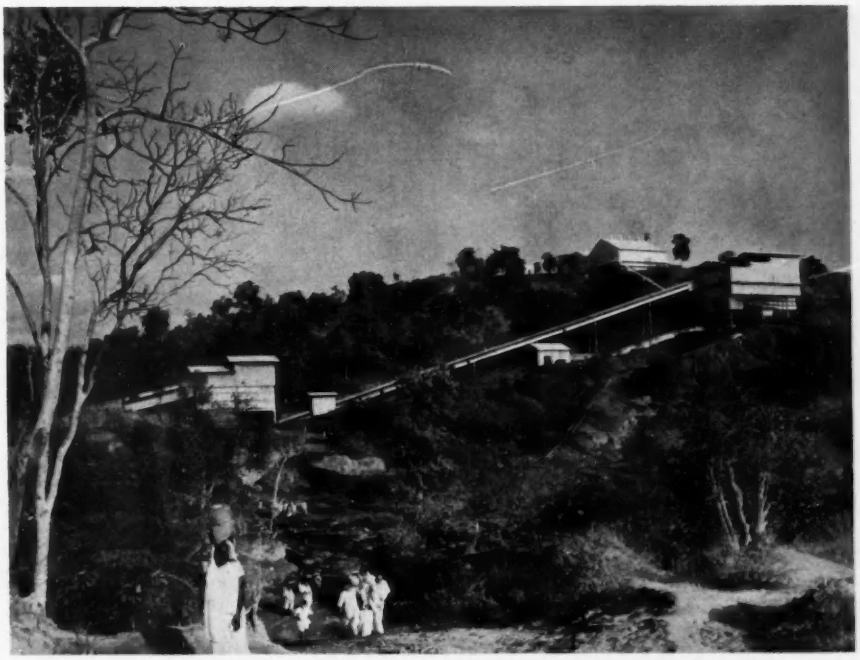

Fig. 1.—General view of the plant showing (left) the run-of-mine coal bunkers, weigher house, main conveyor, washery and, at the top of the hill, the power house.

EQUIPMENT FOR ATOMIC FACTORIES.
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with the same enterprise and foresight which led Jamshedji Tata to lay the foundations of the steel industry in India. The more remote area of the coalfield was closely prospected by this concern and proved to contain many workable coking seams over 7 ft. in thickness. On the basis of this detailed information 13,000 bighas, or approximately $3\frac{1}{4}$ square miles, were acquired on sub-lease by Tata's from the holding company of Bokaro & Ramgur Ltd., for the exclusive purpose of supplying a constituent of the coking blend at their steelworks. A new company, West Bokaro, Ltd., was formed with a capital of $1\frac{1}{2}$ crores of rupees (approximately £1,125,000) and, under the managing agency of Anderson Wright & Co., developments were embarked on. These developments included the provision of a 135-tons-an-hour capacity washing plant.

Shortly afterwards the same concern adopted coal washing as a matter of policy and ordered a second coal preparation plant of 300-tons-an-hour capacity as a central plant for their other collieries. Both are now in satisfactory operation.

Prior to the application of modern coal preparation methods it was customary to prepare coking coal solely from the better seams which, with normal hand picking and screening, gave a product having some 12 per cent to 16 per cent ash. Reserves of coking coal of the better grades are now inadequate to meet the future of the ever-increasing industrialisation of India. Indeed, prior to, and during, the period of planning and construction of this project, the wider problems of Indian national legislation for the conservation of metallurgical coal had been given much thought and attention, and the Tata concern, for many years, had conducted coal research and investigated the possibilities of making usable high and variable ash coking coals, by washing.

It is natural that, with less coal available from the best seams, the trend was not only to a higher ash content but to variations in ash and quality which presented difficult problems to the steelworks management and adversely affected iron production.

This is the background against which Tata planned to assure consistent and adequate coking coal supplies by upgrading the coal from a poorer seam by modern methods and to obtain an unvarying quality for the steelworks.

The venture has fulfilled a pressing need in the face of an inherently difficult problem, not made easier by the remoteness of the site and the necessity of basing plant design on bulk samples taken during colliery development.

Apart from the pioneer nature of the venture, the colliery plant, generally, has several interesting features. West Bokaro is situated in hilly jungle country adjacent to the Bokaro River which here has an elevation of about 1,100 ft. with the surrounding hills rising abruptly about 250 ft. The nearest existing railway at Chainpur station is about five miles away and the contours and intervening river rendered normal means of transport impossible ; this finally led to the adoption of an aerial ropeway over four miles (21,564 ft.) long from the plant to the 1,200-ton-capacity loading bunkers at the railhead on a spur siding. The colliery site and aerial ropeway route are hilly jungle, with a few bullock cart tracks, and are very sparsely populated. The development, therefore, entailed all the work of opening up the colliery, establishing a local village, bazaar, administrative and workers' colony, and brickworks for building construction, apart from the engineering equipment described in this article. In the initial stages all plant, equipment and materials had to be transported 22 miles over indifferent roads, as the direct route to Chainpur at the railhead was impassable to trucks. Indeed, practically all the plant was transported in this manner.

The coal seams lie in the valleys at a shallow depth and at moderate but variable gradients. Near the plant site the area is interrupted by faulting. This causes the upper seam to outcrop in the bed of the stream on the dip side, and on the rise side on the 1,350 ft. contour along the hillside, with a mean vertical distance of 40 ft. between the two horizons.

The plant site was designed to take advantage of these geological features for the installation of conveyors with rotary tipplers for both horizons. Both the conveyors were equipped with booms for discharging into twin raw coal bunkers having a total capacity of 480 tons, the object of the booms being to minimise breakage of the coal and thus avoid an excess of small coal fractions below $\frac{1}{8}$ of an inch and also avoid segregation of sizes.

For rapid development of the mine a 2 ft. gauge track was taken along the 1,350 ft. contour. Adits run in at intervals from the outcrop and link up on an alignment suitable for the permanent installation consisting of a 3 ft. 6 in. gauge track upon which run $2\frac{3}{4}$-ton mine cars, diesel hauled. Consequently, when the installations were completed a large stock of coal was available for processing and despatching and the colliery went into production with a fairly large daily output from modern mining equipment.

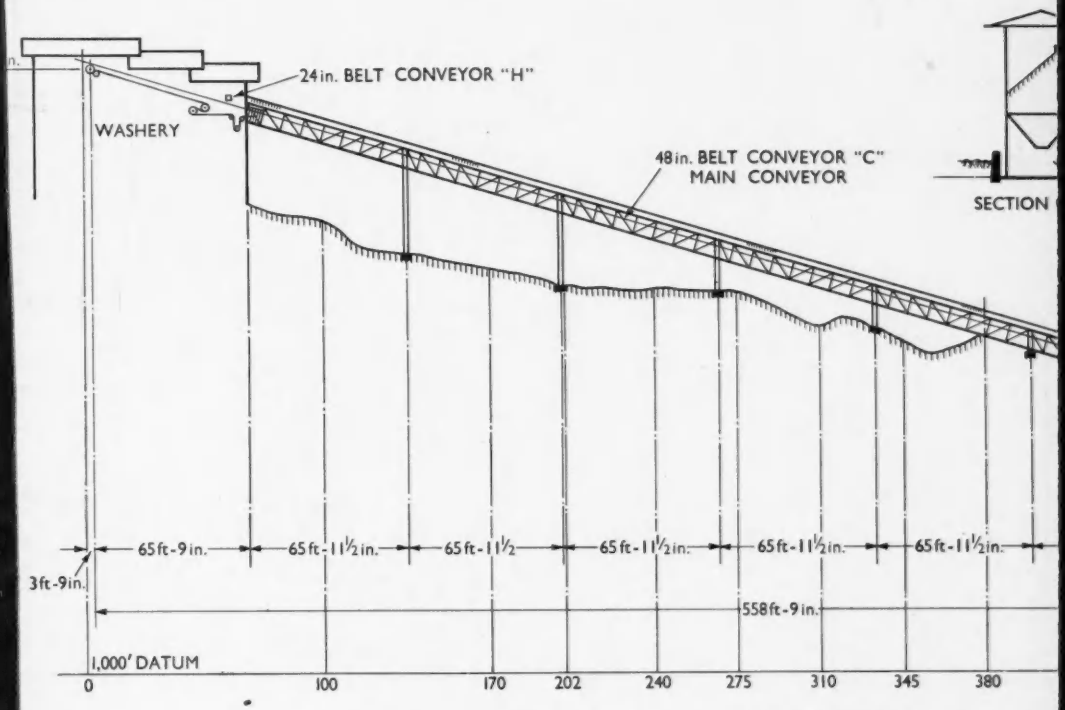
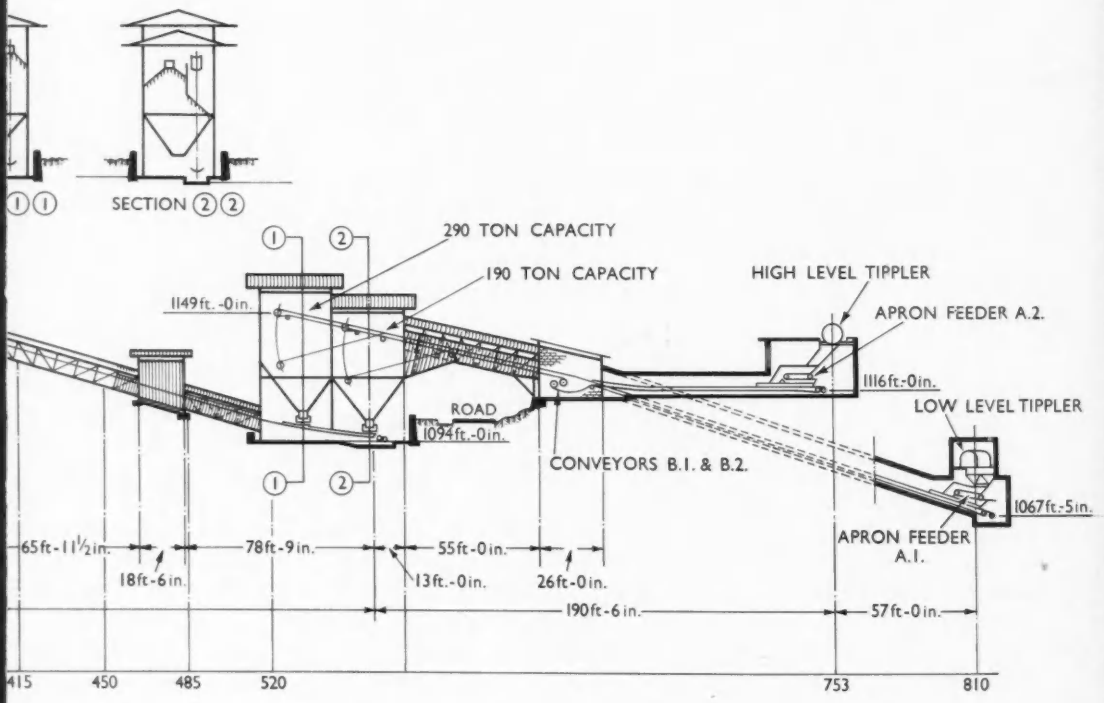


Fig. 2.—Diagram of coal-handling eq



uipment showing elevation of site.

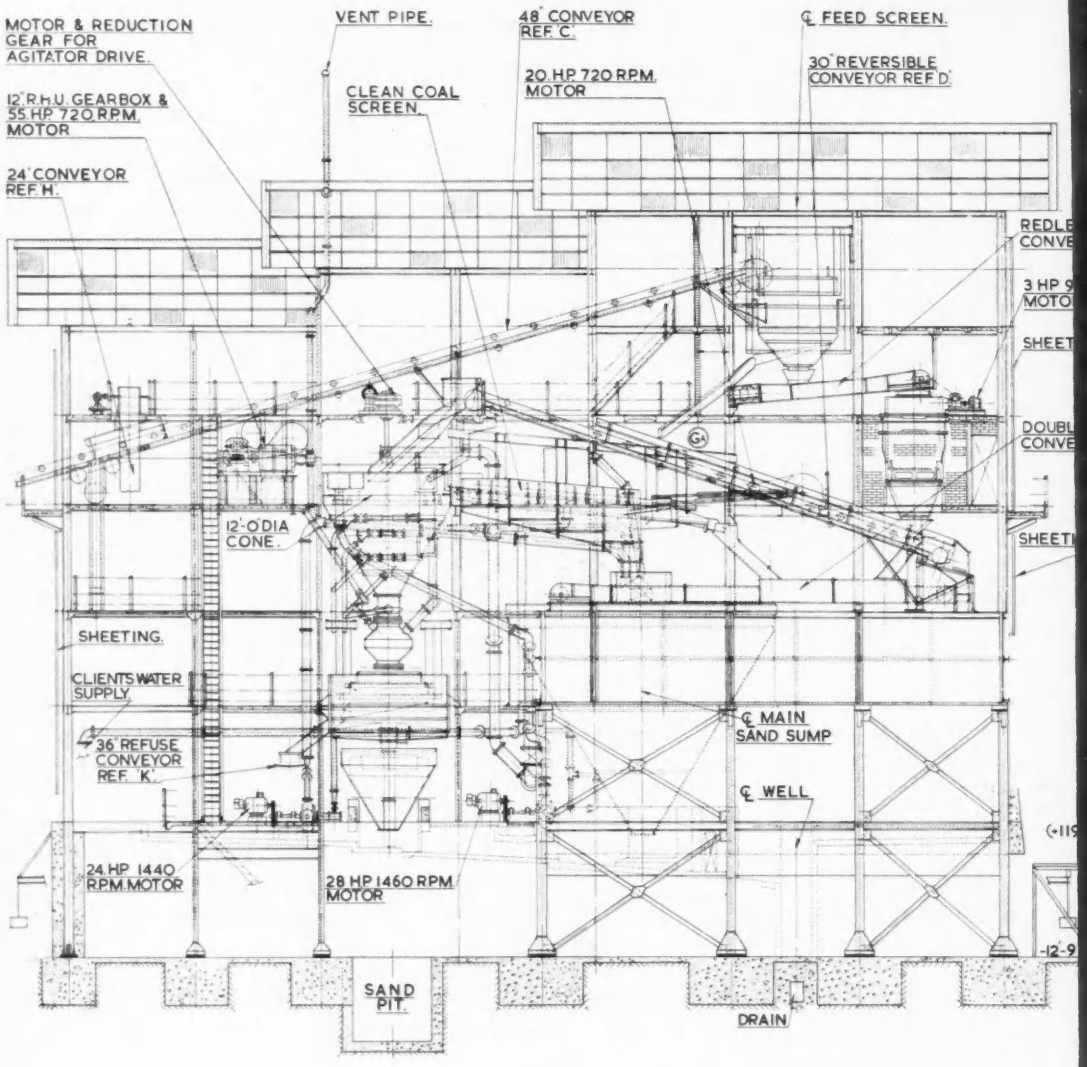


Fig. 3.—General arrangement o

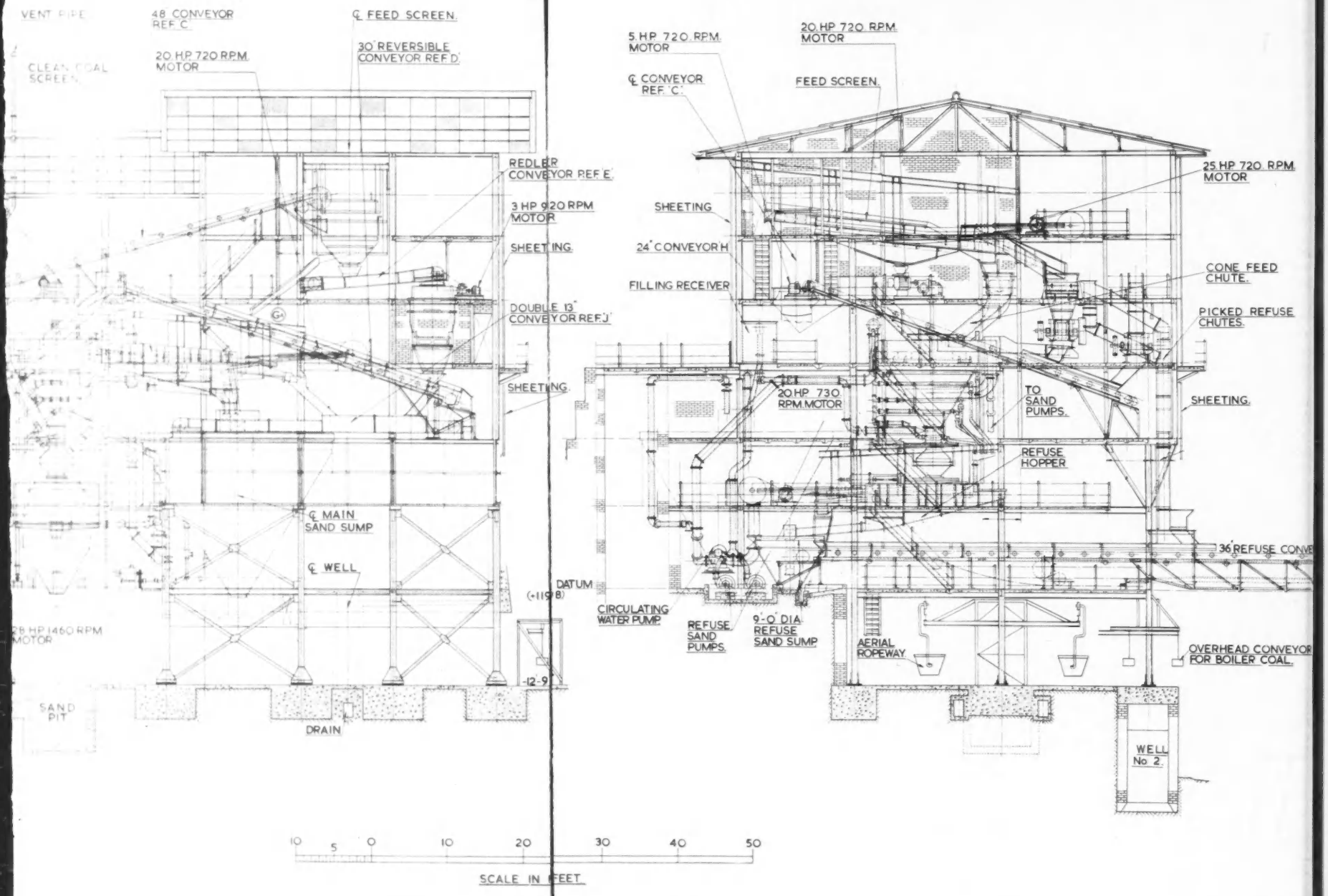


Fig. 3.—General arrangement of washery plant (elevation).

EXTENT OF EQUIPMENT.

The Fraser & Chalmers Engineering Works, in conjunction with their representatives The General Electric Company of India, Ltd., undertook virtually the whole of the engineering equipment for the complete colliery with the exception of the diesel mine locomotives and the ropeway to the railhead.

The whole project centred around the Chance sand flotation coal washer on the commercial and technical efficiency of which the soundness of the development depended. All the mechanical equipment for this and the conveying system from the mine to the washery was constructed at the Company's Erith Works which was also responsible for design and detail drawings of the washery buildings, bunkers and conveyor galleries fabricated in India (figs. 2 and 3).

The power plant comprising steel-framed building and crane, boilers, turbo-alternators and switchgear with associated cables, pipework, spray cooling pond and civil work, was engineered in Calcutta by engineers of the Indian Company. The turbines were built at the Erith Works, the alternators and switchgear at Witton. Major sub-contracts were placed in India for boilers with Babcock & Wilcox, Ltd., power-house building with A. & J. Main, Ltd.; civil work with Jardine, Menzies & Company, and the whole of the washery and conveyor steel fabrication and civil work with Kumardhubi Engineering Works, Ltd.

Supplementing this major equipment were the provision and installation of transformers and overhead transmission lines throughout the property and for mine feeders; lighting for the whole of the plant, office and residential buildings and incidental domestic equipment. Mining type transformers were also supplied for each of the areas developing underground.

The installation was thus unique as a pioneer development, and by virtue of the remote and undeveloped nature of the site called very widely on the broad range of G.E.C. manufactures and also provided a substantial amount of work for local steel fabricators.

CHARACTERISTICS OF RAW COAL.

The coal at West Bokaro, at the present state of development, is 18 to 22 per cent ash, which is unfortunately distributed throughout the whole specific gravity range and there is no clear demarcation, as is usual with most British coals, between the cleaner and dirtier fractions. In order to produce a clean coal of the desired ash content, it is necessary to make a separation at an exceedingly difficult point on the washability curve which gives 67 per cent of material within $\pm$ 0·10 specific gravity of the separation density. This, according to the Bird Classification, comes under the heading of a "formidable" separation problem. Also, due to the fact that the ash is distributed throughout the whole range of the coal, it is impossible to produce a clean coal of less than 7 per cent ash, even with a yield of only 12 per cent.

It is fortunate, therefore, that Indian iron ore is of exceptionally high quality, so that it is possible to operate the blast furnaces satisfactorily with coke having an ash content as high as 21 per cent provided its phosphorus and sulphur contents are reasonably low. This necessitates the production of a clean coal with not more than 15 per cent ash. With the coals at Bokaro, this requires a process capable of making an accurate three-product separation, if a high percentage of discard, containing a correspondingly high percentage of potentially useful combustible material, is to be avoided. By this means it is possible, theoretically, to produce from the raw coal containing 18-22 per cent of ash, a yield of clean coal of approximately 82·5 per cent. The middlings yield would be 6 per cent at 28 per cent ash, and the discard 11·5 per cent at 56 per cent ash.

It also happens that, unlike most British coals, the finer sizes of Indian coals are relatively clean. Thus, it is possible to screen out, say, the minus $\frac{1}{8}$ in. sq. size of raw coal and to mix it back with the plus $\frac{1}{8}$ in. sq. clean coal, and still obtain the ash content demanded by the coke ovens, without resorting to the relatively costly and more difficult problem of cleaning the fines.

The reason for this difference between Indian and British coals is that, in general, the shaley portions of British coals are less intimately mixed with the combustible portion of the coal than is common with Indian coals, and generally occur in relatively thick bands.

As a result of the breaking of the coal during the mining operation, these bands tend to break away from the larger sizes of coal and become concentrated among the finer sizes of coal. Thus, with many British coals, there is a tendency for the ash content of the raw coal to increase with a decrease in size.

Indian coals, on the other hand, do not as a general rule contain bands of soft shale, but consist of bands of high and low ash coal; the high ash fractions being chiefly durain are much less friable than the low ash clarain and fusain fractions. In this way the fines produced as a result of the mining operation tend to have a lower ash content than the larger fractions.

TABLE 1.

FLOAT AND SINK CHARACTERISTICS OF RAW COAL FEED INTO CHANCE CONE AT WEST BOKARO COLLIERY.

Size Sq. Holes	Floats 1·35 S.G. Sinks S.G.			Floats 1·40 S.G. Sinks 1·35 S.G.			Floats 1·45 S.G. Sinks 1·40 S.G.			Floats 1·50 S.G. Sinks 1·45 S.G.			Floats 1·55 S.G. Sinks 1·50 S.G.			Floats 1·58 S.G. Sinks 1·55 S.G.			Floats S.G. Sinks 1·58 S.G.			Total		
	Wt. %	Ash %	Ash Points	Wt. %	Ash %	Ash Points	Wt. %	Ash %	Ash Points	Wt. %	Ash %	Ash Points	Wt. %	Ash %	Ash Points	Wt. %	Ash %	Ash Points	Wt. %	Ash %	Ash Points	Wt. %	Ash %	Ash Points
in. 3 × 1	3·67	8·50	31·2	14·04	11·60	163·0	11·80	18·30	216·0	2·81	21·10	59·3	2·81	29·5	82·9	2·51	35·20	88·4	2·24	60·8	136·2	39·88	19·50	777
in. 1 × ¼	5·64	6·80	38·4	7·87	11·50	90·5	5·31	17·50	92·9	5·32	22·60	120·1	3·93	27·2	107·0	2·01	33·00	66·3	6·74	53·1	357·9	36·82	23·70	873
in. ¼ × ⅛	3·04	5·40	16·4	1·95	11·40	22·2	1·12	17·30	19·4	0·56	21·60	12·1	0·56	28·00	15·7	1·12	34·80	39·0	1·12	54·8	61·4	9·47	19·66	186
in. 3 × ⅛	12·35	6·96	86·0	23·86	11·53	275·7	18·23	18·02	328·3	8·69	22·05	191·5	7·30	28·14	205·6	5·64	34·3	193·7	10·10	55·0	555·2	86·17	21·3	1836
in. — ⅛																						13·83	15·00	208
				Clean coal 63·2 % yield at 12·66 % ash				Yields on +		⅛ in. R.C. to Cone			Middlings 25·1 % yield at 27·2 % ash						Discard 11·7 % at 55% ash			100·0	20·4	2044
Input to cone 3in. × ⅛in.	14·3	—	100	27·7	—	319	21·2	—	381	10·1	—	222	8·45	—	238	6·55	—	225	11·7	—	645	100	21·3	2130

In view of this, it was decided that a dense-medium process was the only one which could accurately separate the coal into three products, i.e. clean coal, middlings and discard down to $\frac{1}{8}$ in. size, and allow the minus $\frac{1}{8}$ in. material to be mixed back with the washed clean coal thereby giving a maximum recovery of coking coal at the required ash content.

After extensive investigation at home and abroad and a study of the operating results in South Africa, where the characteristics of the coals are rather similar, the Chance sand flotation process was decided upon.

Serious investigation of the site began in 1940 but the complete contract was not finalised until 1947. During this period a large sample of the raw coal was shipped to Britain for testing in the commercial size test plant which was available at the Erith Works, and other tests were carried out in India by a ' sink and float ' test machine.

It is common knowledge that with a given washery it is possible to obtain a much greater throughput if the coal is treated in large rather than in small pieces. As a result of the investigations at Erith with the Bokaro coals, however, it was found that while the run-of-mine coal consists of fractions which gradually change from low to high ash, a percentage of lower ash coal would be realised on crushing. It was therefore decided that the most economical arrangement, both from the point of view of yield and capital cost, was to crush the R.O.M. coal to minus 3 in. rd. and wash the 3 in. $\times \frac{1}{8}$ in. fraction in the Chance cone, mixing the minus $\frac{1}{8}$ in. sq. fraction back untreated, in the manner already described.

It was also found that the yield of clean coal could be improved to some extent by crushing the larger middlings and re-washing. The design of the plant, therefore, included facilities to screen the 3 in. $\times$ 1 in. from the 3 in. $\times \frac{1}{8}$ in. middlings, leaving the 1 in. $\times \frac{3}{8}$ in. fraction to be loaded out as a boiler fuel, while the 3 in. $\times$ 1 in. is crushed to minus 1 in. and re-circulated with the raw coal feed for re-washing.

The characteristics of the raw coal as delivered into the Chance cone at the time when the plant was being commissioned are given in Table 1, while the washability curve is given in fig. 4, together with that for a typical British coal for purposes of comparison.

THE CHANCE WASHER.

The washery has a maximum input to the 12 ft. dia. Chance cone of 127 tons an hour and is arranged as shown on the flow sheet (fig. 5).

Coal handled in mine cars, drawn by diesel locomotives, is discharged on to two apron feeders *A*1 and *A*2. The feeders discharge to belt conveyors *B*1 and *B*2 respectively, which are fitted with adjustable booms at the delivery end to deliver the run-of-mine coal into two raw coal bunkers, one of 190-ton and the other of 290-ton capacity. This arrangement, besides evening out the feed to the washery, enables some blending of the coals to be accomplished, should this prove to be desirable. The raw coal bunkers are each fitted with a Sherwen electro-magnetically vibrated feeder, 4 ft. wide $\times$ 10 ft. long, with a capacity of 50/135 tons an hour each, and remotely controlled from the washery building. Each Sherwen feeder discharges to the main raw coal conveyor *C* which is fitted with an automatic weigher. The conveyor delivers raw

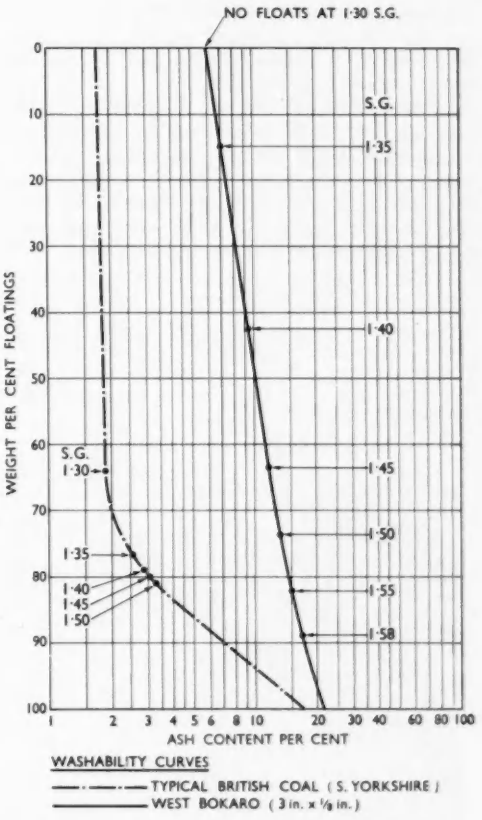


Fig. 4.—Washability curve for 3 in. $\times \frac{1}{8}$ in. raw coal as delivered into the Chance cone.

coal to the triple-deck primary screen which classifies it into the following sizes :

R.O.M. × 3 in. rd.
3 in. rd. × ½ in. rd.
½ in. rd. × 0.

The R.O.M. × 3 in. rd. fraction is delivered on to the plate picking belt, reference *F*, while the 3 in. rd. × ½ in. rd. fraction is discharged on to belt conveyor, reference *D* (fig. 5). Meanwhile the ½ in. × 0 material is discharged into a Fraser & Chalmers Redler conveyor, reference *E*, which, in turn, delivers this material to a 10 ft. × 4 ft. Sherwen screen for dry screening at ⅛ in. sq.

The ' throughs ' from the Sherwen screen are collected in a suitable hopper whence this ⅛ in. sq. × 0 material may be discharged directly into the dust bunker, for loading as a separate product, or alternatively to the Redler conveyor, reference *J*, for mixing with the 3 in. rd. × ⅛ in. sq. clean coal. The ½ in. rd × ⅛ in sq. fraction is discharged from the Sherwen screen to the conveyor, reference *D*, for delivery to the Chance cone along with the 3 in. rd. × ½ in. rd. material for washing.

Should it be decided not to clean the ⅜ in. rd. × ⅛ in. fraction, arrangements have been made whereby all ⅜ in. × 0 material may be delivered down the back of the Sherwen screen hopper and thence either directly into the dust bunker or, alternatively, to the clean coal conveyor, reference *J*, for mixing with the clean coal.

The R.O.M. × 3 in. rd. material, as already described, is delivered on to the plate picking belt, reference *F*, for the removal of any large pieces of stone, tramp iron and so forth, after which the raw coal is discharged into a Pennsylvania single roll crusher for reduction to minus 3 in. rd. This crushed material is then recirculated into the system via conveyors *H* and *C* and washed as already described.

Conveyor *D* has been arranged so that it may be reversed in the event of the washery's being out of commission for any reason, in which case a 3 in. × ⅛ in. hand-cleaned coal would be delivered directly to the middlings bunker for disposal by means of the aerial ropeway.

The operation of the Chance plant, which is arranged for a three-product separation, namely clean coal, middlings and refuse, is so well known that it requires no elaboration other than a reminder that the medium consists of sand kept in a state of " balanced hindered settling " by a low upward velocity of water.

The clean coal overflows from the top of the cone, together with a certain amount of sand and water, which is separated from the coal on a slow speed reciprocating screen. The middlings are extracted from a point midway down the cone by means of a middlings column, and de-sanded and de-watered in a like manner (fig. 7). Meanwhile the refuse is extracted from the base of the cone by means of two air-operated gates working on an automatic cycle (fig. 8).

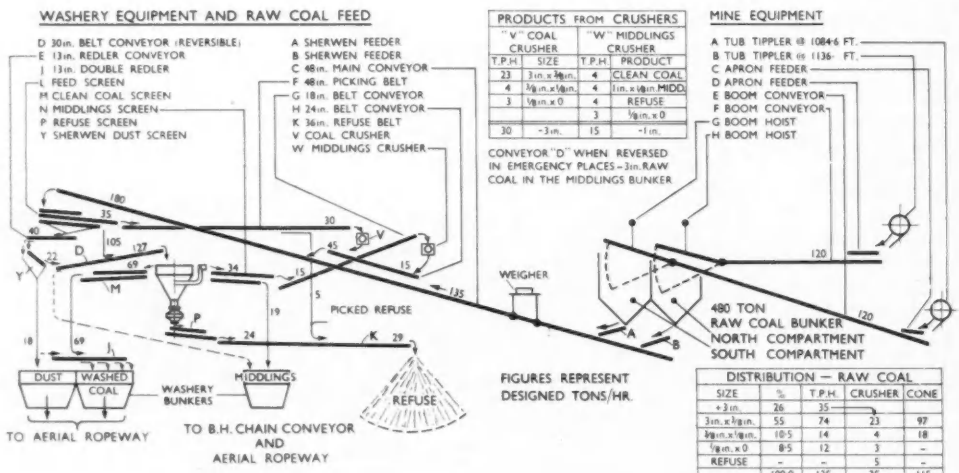

WASHERY EQUIPMENT AND RAW COAL FEED
D 30in. BELT CONVEYOR (REVERSIBLE)
E 13in. REDLER CONVEYOR
J 13in. DOUBLE REDLER
L FEED SCREEN
M CLEAN COAL SCREEN
N MIDDLINGS SCREEN
P REFUSE SCREEN
Y SHERWEN DUST SCREEN
A SHERWEN FEEDER
B SHERWEN FEEDER
C 48in. MAIN CONVEYOR
F 48in. PICKING BELT
G 18in. BELT CONVEYOR
H 24in. BELT CONVEYOR
K 36in. REFUSE BELT
V COAL CRUSHER
W MIDDLINGS CRUSHER
PRODUCTS FROM CRUSHERS
"V" COAL CRUSHER
"W" MIDDLINGS CRUSHER
T.P.H. SIZE T.P.H. PRODUCT
23 3in. x ⅜in. 4 CLEAN COAL
4 ⅜in. x ⅛in. 4 1in. x ⅛in. MIDD
3 ⅛in. x 0 4 REFUSE
3 ⅛in. x 0
30 -3in. 15 -1in.
CONVEYOR "D" WHEN REVERSED IN EMERGENCY PLACES - 3in. RAW COAL IN THE MIDDLINGS BUNKER
MINE EQUIPMENT
A TUB TIPPLER @ 1084·6 FT.
B TUB TIPPLER @ 1136· FT.
C APRON FEEDER
D APRON FEEDER
E BOOM CONVEYOR
F BOOM CONVEYOR
G BOOM HOIST
H BOOM HOIST
WEIGHER
PICKED REFUSE
480 TON RAW COAL BUNKER
NORTH COMPARTMENT
SOUTH COMPARTMENT
DUST
WASHED COAL
WASHERY BUNKERS
MIDDLINGS
REFUSE
TO AERIAL ROPEWAY
TO B.H. CHAIN CONVEYOR AND AERIAL ROPEWAY
FIGURES REPRESENT DESIGNED TONS/HR.
DISTRIBUTION — RAW COAL
SIZE % T.P.H. CRUSHER CONE
+3in. 26 35
3in. x ⅜in. 55 74 23 97
⅜in. x ⅛in. 10·5 14 4 18
⅛in. x 0 8·5 12 3 -
REFUSE - - 5 -
100·0 135 35 115
MIDDLINGS - 30 15 12
TOTAL - - - 127

Fig. 5.—Flow sheet, West Bokaro coal preparation plant.

Fig. 6.—At the top of the washery: (extreme left) conveyor feeding 3 in. × 1 in. middlings to the crusher; (centre) the plate inspection belt; and (right) the main feed belt to the cone.

A diagrammatic arrangement of a Chance cone, suitable for a three-product separation is illustrated in fig. 9. A special feature of the process is that by means of a simple operation, taking only a few minutes, the cone can be adjusted to make a two-product separation, if this should be desirable, to meet changes in the characteristics of the raw coal, or for market requirements.

The refuse from the Chance cone, after de-sanding and de-watering, is discharged on to conveyor *K*, which also receives the picked-off dirt from the picking belt *F*. Conveyor *K* discharges into a refuse bunker from which the accumulated refuse is removed by trams. More recently the bunker has been fitted with a Sherwen feeder which places the refuse on a mining type conveyor with an extending head. This conveyor discharges into a valley a short distance from the plant, which was selected because no coal seams outcrop on its slopes.

Fig. 7.—The top of the cone with gravity control valves on the left of the middlings trough (right foreground.)

The clean coal, after de-sanding and de-watering, is delivered to a double Redler conveyor, reference *J*, which is also arranged for receiving $\frac{1}{8}$ in. sq. × 0 dust, and delivering the mixed product to the washed coal bunker. The section of this conveyor, which is situated immediately over the bunker, is arranged with a continuous open discharge in order that the bunker may be self-trimming.

Meanwhile, the middlings are de-sanded and de-watered on a separate middlings screen which is also arranged for sizing at 1 in. rd. The 1 in.

rd. × ⅛ in. sq. material is discharged directly into the middlings bunker while the 3 in. rd. × 1 in. rd. material is discharged on to conveyor, reference *G*, and thence to a second Pennsylvania single roll crusher for reduction to minus 1 in. rd. This crushed material is then re-circulated into the system via conveyors *H* and *C* for re-washing.

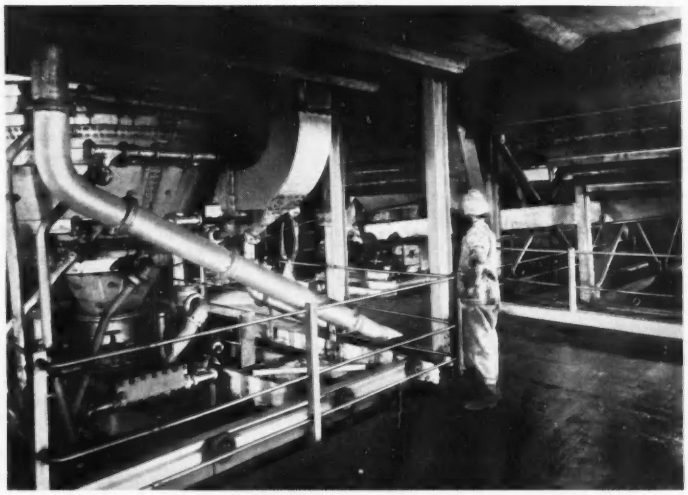


Fig. 8.—Base of the cone with (bottom left) the top refuse gate and (centre) the middlings column.

Compressed air for the operation of the refuse gates of the Chance cone is supplied by means of a two-stage electrically driven compressor, which, for convenience in maintenance and for the supply of service air, is situated inside the power house. The machine is capable of delivering 150 cu. ft. of free air a minute at a pressure of 80 lb. per sq. in.

Make-up water for the Chance plant is taken from the condenser cooling ponds, which are situated at a higher level than the washery, so that it is possible to supply the water by gravity. A small pump is provided, however, for supplying high-pressure water for sealing the various pump glands. The average quantity of make-up water required is about sixty gallons a minute.

OPERATING RESULTS.

The guaranteed washing errors when operating as a two-gravity unit, with a duty of up to 135 tons an hour, are given in Table 2. In addition, the results of a test, which was carried out soon after the plant went into commission, are shown, and it will be seen that the percentage errors are comfortably within the guarantees with this extremely difficult coal. It should be noted that in each case the percentage errors

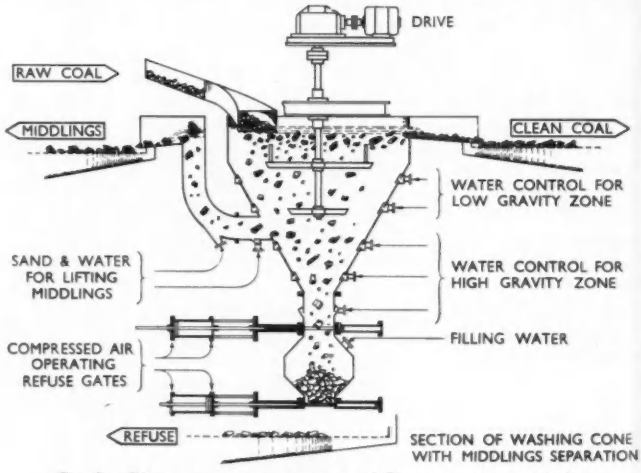


Fig. 9.—Diagrammatic arrangement of Chance cone suitable for three-product separation.

refer to the raw coal input to the Chance cone.

The sand consumption was also within the guaranteed figure of 3 lb. per ton of raw coal, and it is interesting to note that at Bokaro, like all other Chance washery sites the world over, no difficulty was experienced in obtaining a natural sand of suitable grading, without any prior classification or preparation being necessary.

The various products from the washery are, as already noted above, discharged into bunkers which have the following capacities :

Dust	... ...	65 tons
Clean Coal	...	170 tons
Middlings	...	250 tons

All these bunkers are arranged to discharge into ropeway buckets for delivery to the railhead, in the manner already described.

POWER GENERATION EQUIPMENT.

The power plant (fig. 10) has been designed with a simplicity of layout to give a high degree of reliability with a minimum of operating attention, appropriate to a remote district and low fuel costs. There is no interconnected electrical supply with the Power House, and the plant as installed provides a one hundred per cent standby.

Two boilers, together with two 1,000 kW M.C.R. turbo-alternators designed for steam conditions of 240 lb./sq. in., 625 deg. F, are provided, the turbines running at a speed of 7,000 r.p.m. and geared to salient pole alternators running at 1,500 r.p.m. The supply is at 550 volts, 50 cycles, 3-phase with a power factor of 0·8.

The boilers are of the universally known Babcock & Wilcox W.I.F. type, incorporating enclosed chain grate stokers with forced and induced draught designed for burning middlings fuel. For the first time in India a prepared middling quality fuel of approximately 27 per cent ash was available and the combination proved to be excellent.

Handling coal to the boiler house presented a problem overcome in a unique way. The colliery domestic requirements were a small proportion of the middlings fuel which had to be taken from an elevation of 1,190 ft. under the plant bunkers to 1,270 ft. over the boiler stoker hoppers, the only practical route being at a steep angle up the hillside clearing the main ropeway en route. Nearly all plants of this capacity requiring only 1 to 2 tons an hour in India are fed by hand labour, but the route was too great a handicap. The small tonnage of some 40 tons a day enforced a low capital cost. Reserve storage available in the washery plant bunkers made duplication of large storage adjacent to the boilers unnecessary. The problem was solved by a fully automatic Fraser & Chalmers chain conveyor with a track length of 800 ft. This conveyor consists of a single 6 in. × 3 in. rolled-steel track, carrying bottom dumping buckets, supported on sealed ball bearing double-wheeled trolleys (fig. 11). The latter are coupled by means of an articulated chain, running at a

TABLE 2.

COMPARISON OF ACTUAL WASHING ERRORS WITH GUARANTEED WASHING ERRORS

Product	Actual		Guaranteed	
	Error Wt. %	Total Error at Separating Density Wt. %	Error Wt. %	Total Error at Separating Density Wt. %
Sinks in Clean Coal at 1·45 S.G.	4·0	6·8	8·0	13·0
Floats in Middlings at 1·45 S.G.	2·8		5·0	
Sinks in Middlings at 1·60 S.G.	5·6	6·4	3·0	5·0
Floats in Refuse at 1·60 S.G.	0·8		2·0	
Total		13·2		18·0

NOTE.

The percentage errors in each case refer to the raw coal input to the Chance cone.

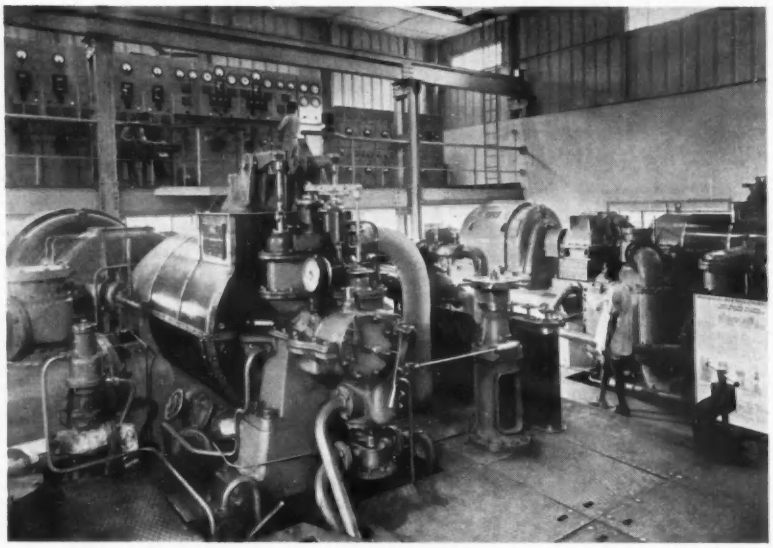


Fig. 10.—Generating station showing the two 1,000 kW turbo-alternators and control gear.

speed of 12 ft./min., at intervals of 25 ft.; the buckets each have a capacity of 123 lb. The maintenance of this conveyor is extremely low, due to the low speed and minimum friction, and only 2 h.p. is required for driving purposes. The buckets are automatically filled from either of two 18 in. wide × 3 ft. long Sherwen feeders, under the middlings coal bunker, which are adjusted to fill a measured quantity into each bucket as it passes, the operation being controlled by means of limit switches operated by the buckets.

At the Boiler House end the bottom doors of the buckets are tripped open over any stoker

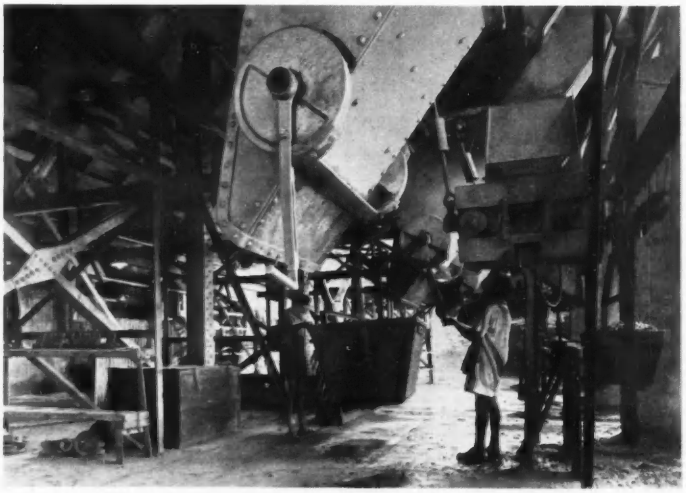


Fig. 11.—Under the main bunkers showing the main ropeway buckets and, on the right, one of the buckets of the boiler coal conveyor.

hopper, as desired (fig. 12). A small surge bunker is provided at ground level in the Boiler House to take any spill over from the hoppers and so avoid a full bucket being returned during a period when the conveyor capacity is in excess of the boiler requirements. The conveyor may be started or stopped by means of push buttons controlled by the Boiler House attendant, while, for convenience in servicing, a further set of push buttons is provided near the feed end of the conveyor at the washery.

This small coal loading system is therefore unique, since it requires little or no operational attention, and provides an entirely automatic service at the disposal of the boiler attendant.

The turbines and alternators are of the non-basement type, arranged with a condenser integral with the turbine exhaust casing. The equipment is laid out in such a way as to give maximum accessibility and a minimum of operating attention. The alternators are of the enclosed type and are equipped with viscous type air filters flush with both sides of the foundation plinth and the hot air is discharged outside the power house through a concrete duct.

The generation voltage of 550 was chosen because it is a standard in Indian coalfields, and is therefore advisable for mining equipment. The bulk of the power is used in the nearby washery, so that only a small proportion is transformed up to 3·3 kV for transmission to distant parts of the property.

The two alternators, which are provided with automatic voltage regulators, are controlled from the 550 volt main switchboard which is of the standard S.V.D. type with oil circuit breakers arranged for vertical isolation. This board also controls the principal feeders to the mine, washery, raw coal handling plant and the 120 h.p. motor driving the aerial ropeway. The auxiliary board is of the airbreak type arranged to serve both as a feeder board to the minor circuits and lighting transformers, and also as a centralised auxiliary motor starting board. It is of sheet steel cubicle type construction with five panels, each having a compartment above and below centrally arranged busbars, housing two contactors with interlocked

Fig. 12.—The boiler house with buckets of the chain conveyor passing over the stoker hoppers.

isolators. These contactors are used as direct-to-line starters for the Power Station auxiliary motors. The board is also equipped with a Nife type tripping battery and charging cabinet.

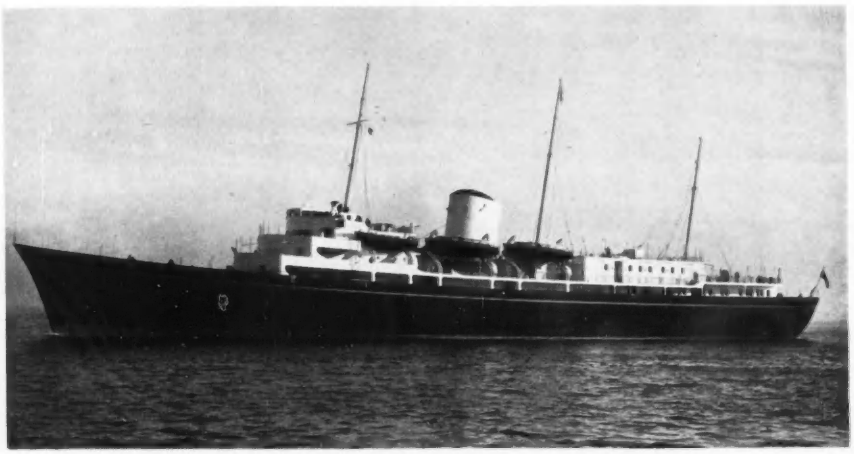
The emergency lighting equipment is worthy of mention, as it is simple, inexpensive, reliable and requires little maintenance. It comprises a 2 kW steam turbo-generator of the constant-voltage type, as used for locomotive headlights, with the generator permanently switched on to a separate emergency lighting system. The equipment is arranged adjacent to the boiler feed pumps and, in the event of a failure of the main lighting system, it is necessary for the boiler operator only to open one valve to obtain emergency lighting in a few seconds.

In order to simplify the pumping arrangements, the water storage and cooling scheme for the power plant has been co-ordinated with the requirements of the washery. The nature of the ground allows of a cooling pond, placed conventionally alongside the Turbine House, to have a static head suitable for refilling the washery, when required, and for normal make-up. The water requirements of the whole of the plant are thus fed by way of the Power House cooling pond. The colliery water supply from a number of sources is pumped to a filter plant adjacent to the cooling pond and, with the pond acting in the capacity of a surge tank, can be at an appropriate average rate. An additional water head and reserve storage required for the boiler feed make-up is provided by a circular concrete tower located within the area of the cooling pond. This is fed from a tapping from the circulating water pumps delivering to the spray cooler, an arrangement which is economical in equipment and space and provides spill-over into the surrounding pond.

ACKNOWLEDGMENT.

For much of the information in this article the authors are indebted to Mr. Andrew Farquhar A.R.T.C., Coal Adviser to the Tata Iron and Steel Co. and Technical Director of West Bokaro Ltd., who for thirty years has devoted much of his time and experience to the treatment and conservation of Indian metallurgical coals.

The Royal Yacht



Special lighting fittings have been supplied for the Royal and State Apartments in H.M.Y. Britannia. In addition, twenty-five floodlights have been made for flood-lighting the funnels, masts, flags and upper deck.

High-Pressure Mercury Vapour Fluorescent Lamps

By H. G. JENKINS, M.Sc., F.Inst.P. and A. H. McKEAG, M.Sc., A.R.I.C.
G.E.C. Research Laboratories.

Because of its lack of red radiation, the colour rendering of the H.P.M.V. discharge is poor. The first practical colour-corrected H.P.M.V. lamp using a red fluorescing coating on the outer bulb was developed at the G.E.C. Research Laboratories, Wembley, in the early 1930's.

The present article is the substance of a paper read before the Association Française des Eclairagistes at Dijon in May, 1953, and published in the Proceedings of the Convention. It deals with recent developments in this type of lamp which have been made possible by the discovery of new red fluorescing phosphors.

1. INTRODUCTION.

THE problem of improving the colour-rendering properties of high-pressure mercury discharge lamps has received considerable study during the past twenty years. The requirement is mainly one of adding red light in which the mercury discharge is deficient. Various methods of approach have been suggested, including : (1) The addition of other metals such as zinc and cadmium to the mercury discharge. (2) The combination of an incandescent filament mounted in the same bulb as the discharge lamp. (3) A coating of a suitable red phosphor on the inside surface of the outer bulb of the lamp.

The last-named method, which utilises the ultra-violet energy in the discharge, is the only one which does not involve a serious loss in luminous efficiency.

The use of fluorescent dyes, such as rhodamine, to improve the colour of mercury lamps, was suggested as early as 1903 by Burke,[1] and attempts were made to apply this principle in the Cooper Hewitt lamp using celluloid films stained with rhodamine. Unfortunately, such materials are impermanent and it was not until 1932, when Ryde[2] proposed the use of zinc cadmium sulphides, that a colour-corrected H.P.M.V. lamp became a practical possibility. Lamps of 400 watt rating were marketed in Great Britain in 1937 and gave an efficiency of 38 L/W with about 5 per cent red. The inner glass discharge tube of these lamps transmitted only the long wavelength ultra-violet. Cadmium was used with the mercury to provide additional red and blue light.

In 1939 sulphide-coated bulbs were used with 80 watt and 125 watt quartz H.P.M.V. lamps. Although the quartz tube transmitted the ultra-violet radiation to about 2,000 Å, this was not utilised to any extent because of the excitation characteristics of the sulphide phosphor. More recently lamps coated with phosphors other than sulphides have been developed and an appraisement of the factors which have brought about these changes will be given in the later sections of this article, which describes some of the recent advances which have been made in H.P.M.V. fluorescent lamps.

2. SPECTRAL ENERGY DISTRIBUTION OF H.P.M.V. LAMPS.

It is well known that the effect of increasing the mercury vapour pressure in a mercury vapour discharge is to reduce the output of the mercury resonance line at 2,537Å and to increase the amount of long wave ultra-violet and visible radiation. Although the intensity of the 2,537Å line in the ultra-violet is reduced, a study of the spectral energy distribution curve (fig. 1) of a 125 watt H.P.M.V. lamp, with the outer glass bulb removed, shows that the energy radiated between 2,000 and 3,800Å is still considerable and is more than fifty per cent greater than the total energy radiated in the visible. The approximate distribution of energy in bands is given in the top row of Table 1.

If each of these bands of ultra-violet energy

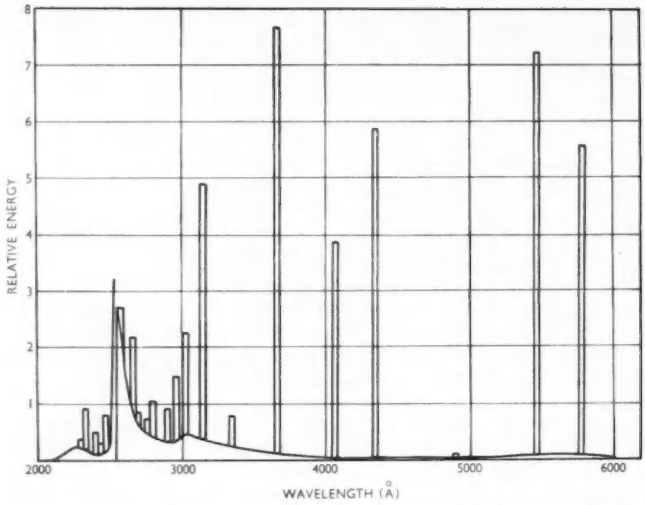


Fig. 1.—Spectral distribution of 125 watt quartz H.P.M.V. lamps without an outer bulb.

is transformed into red light of wavelength 6,500Å by means of a luminescent powder coating and without loss in the phosphor, the amount of energy available as red light of wavelength 6,500Å is given to a sufficient order of approximation, by $\frac{E\lambda_c}{6{,}500}$ where E is the energy in the band and λ_c is the centre wavelength of the band. The values so obtained for each band are shown in the second row of Table 1 and the total for all the ultra-violet bands amounts to 9·0 watts. It may be shown that the theoretical maximum efficiency of light of wavelength 6,500Å is 62 L/W so that 9·0 watts of power correspond to 558 lumens of red light.

The quantum efficiency of a phosphor may be as high as 90 per cent but in an H.P.M.V. lamp operating at a relatively high temperature the figure is probably not greater than 80 per cent. This reduces the figure of 558 to 446 lumens, and expressing this as a percentage of 5,000, the total lumens from the 125 watt lamp (40 L/W), it is seen that a red ratio of 8·9 per cent is obtained (see Section 7). Adding to this the red ratio of the mercury lamp itself which amounts to 1·7 per cent, gives a value of 10·6 per cent at an efficiency of 40 L/W as theoretically possible. The difference between these figures and the values actually achieved may readily be accounted for by additional losses in the fluorescent coating due to scattering and absorption.

The initial red ratio of the present 400 watt glass H.P.M.V. lamp would be poorer than this because of the absorption of radiation below 3,000Å by the glass walls of the discharge tube, and also because the red ratio of the discharge itself is lower than in the quartz lamp. An approximate figure for the glass lamp based on a cut-off at 3,000Å for the envelope gives a corresponding figure for the red ratio of about 7 per cent.

3. DESIRABLE PHOSPHOR CHARACTERISTICS.

It will be evident from the foregoing discussion that the achievement of figures approaching those theoretically possible demands a phosphor with a number of special properties. These may be summarised as follows:

(*a*) The phosphor should emit predominantly orange or red light. Some emission in the blue or blue-green may also be an advantage.

TABLE 1.

DISTRIBUTION OF ULTRA-VIOLET ENERGY IN 125 WATT QUARTZ H.P.M.V. LAMP.

	2,000Å-2,500Å	2,500Å-3,000Å	3,000Å-3,500Å	3,500Å-3,800Å
Energy distribution in U.V. bands	1·8 watts	7·1 watts	5·7 watts	4·6 watts
Energy in U.V. bands transformed into visible radiation at 6,500Å	0·6 watts	3·0 watts	2·8 watts	2·6 watts

TABLE 2.

THE MORE IMPORTANT RED PHOSPHORS.

Phosphor	Chemical Formula	Activator	Excitation Range
Zinc cadmium sulphide	(Zn,Cd)S	Cu	Primarily long U.V.
Cadmium borate	$Cd_2B_2O_5$	Mn	Short U.V.
Calcium halophosphate	$3Ca_3(PO_4)_2Ca(F,Cl)_2$	SbMn	Short U.V.
Calcium orthophosphate	$Ca_3(PO_4)_2$	CeMn	Short U.V.
Magnesium fluogermanate	$Mg_8Ge_2FO_{11}$	Mn	Long and short U.V.
Magnesium arsenate	$Mg_6As_2O_{11}$	Mn	Long and short U.V.
Barium strontium lithium silicate	$(Ba,Sr,Li_2)_2SiO_4$	CeMn	Long and short U.V.

(*b*) The emission should be maintained at temperatures of 150 deg. C. or greater.

(*c*) The excitation spectrum of the phosphor should extend over the emission range of the H.P.M.V. mercury spectrum, i.e. from 2,000-3,800Å and throughout this range the quantum efficiency of the phosphor should be as high as possible under the operating conditions of the lamp.

(*d*) The phosphor should be colourless.

(*e*) It should be stable during processing and subsequent operation of the lamp.

(*f*) Other practical considerations, such as cost, availability of raw materials and ease of production must also be considered.

In view of these stringent conditions it is perhaps remarkable that three distinct phosphor groups have recently been discovered which fulfil most of these conditions reasonably well. A survey of the available red phosphors and the selection of the most suitable will illustrate the present position.

4. RANGE OF SUITABLE PHOSPHORS.

In Table 2 is given a list of the more important phosphors which deserve consideration. A number of red phosphors, e.g. $CdWO_4$(U) (Zn, Cd)S(Ag), have been excluded from the choice because of their poor temperature characteristics.

The first four phosphors listed in the table are strongly excited by part only of the ultra-violet spectrum and are, therefore, incapable of utilising completely the available ultra-violet energy. Lamps using these phosphors have given red ratios of between a third and a half of the theoretical maximum value.

The last three phosphors only will be considered in what follows. These are of recent origin and, having broad excitation bands, are potentially capable of more efficient utilisation of the ultra-violet radiation with correspondingly better performance when used with quartz H.P.M.V. lamps.

(*a*) Magnesium Fluogermanate.

This phosphor which derives from double ortho magnesium germanate Mg_4GeO_6[3] is described by Thorington.[4] It is formed from the latter compound by replacing a small part of the magnesium oxide by magnesium fluoride and is more efficient than the straight germanate phosphor. The colour of the fluorescence, which is a bright red at room temperatures, becomes somewhat more orange at higher temperatures. It has a pale-yellow body colour which becomes more pronounced at higher temperatures.

(*b*) Magnesium Arsenate.

The magnesium arsenate phosphor, described by Travnicek, Kröger, Botden and Zalm[5], resembles in many respects the fluogermanate phosphor. Like the fluogermanate, it contains a higher proportion of magnesium oxide than the conventional ortho compound. It has a pale-yellow body colour and gives a red emission similar to magnesium fluogermanate.

(*c*) Barium Strontium Lithium Silicates.

This group of phosphors,[6] unlike the fluogermanate and arsenate phosphors, gives rise to a range of colours comprising blue, orange and red or intermediate shades of these colours. The end members of the series comprise barium lithium silicate and strontium lithium silicate,

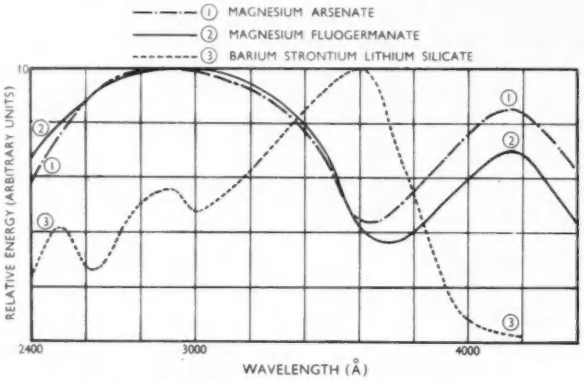


Fig. 2.—Excitation spectra of red phosphors.

and a continuous series of solid solutions of barium strontium lithium silicates can be formed with a progression of luminescent properties. The group, as a whole, comprises another example of a double-activated system. The primary activator, cerium, gives a characteristic blue emission by itself, and acts as a sensitiser for the secondary activator, manganese. As the manganese content is increased the blue emission is reduced in intensity and the characteristic manganese band in the orange or red develops. With a barium lithium silicate composition the colour of the manganese emission is orange and the colour becomes redder as strontium atoms replace the barium atoms. At higher temperatures the colour of the fluorescence shifts towards the yellow with those phosphors which contain manganese.

Unlike the fluogermanate and arsenate phosphors, these silicate phosphors are prepared in reducing conditions to form trivalent cerium in the lattice. They are almost white in body colour.

5. PHYSICAL PROPERTIES OF THE NEW RED PHOSPHORS.

(*a*) Excitation Spectra.

The excitation spectra were measured by means of a quartz monochromator, selecting wavelengths of exciting radiation from the spectrum of a quartz jacketed 125 watt H.P.M.V.-type lamp. The energies of the various ultra-violet lines are measured by means of a Schwartz thermopile. The emitted fluorescent light, after passing through a filter to remove any residual exciting radiation, is measured by a multiplier photocell. The excitation spectrum is obtained by dividing the fluorescent light intensity by the appropriate incident energy value.

The remarkable similarity in properties between magnesium arsenate and magnesium fluogermanate, already mentioned, is further exemplified in the excitation and emission spectra of these two phosphors shown in figs. 2 and 3. Two excitation bands occur, with the main one having its maximum at about 2,900Å. A trough occurs at 3,700Å and the second excitation band has a maximum at about 4,200Å. The ratio of the relative heights of these bands depends to some extent on the method of preparation of the phosphor. The second excitation band overlaps into the visible and is responsible for the yellowish body colour of the phosphors.

The excitation spectra of the barium strontium lithium silicate phosphors are of a different character from those just described. The main excitation maximum occurs in the long wavelength ultra-violet region at about 3,600Å, while at shorter wavelengths two smaller maxima occur at about 2,500Å and 2,900Å. The main band terminates close to the limit of visible radiation and consequently does not produce appreciable body colour. From the general shape of these curves, assuming that the energy conversion processes in the different phosphors are equally efficient, it may be expected that the arsenate and fluogermanate phosphors would perhaps lead to a fuller utilisation of the available ultra-violet

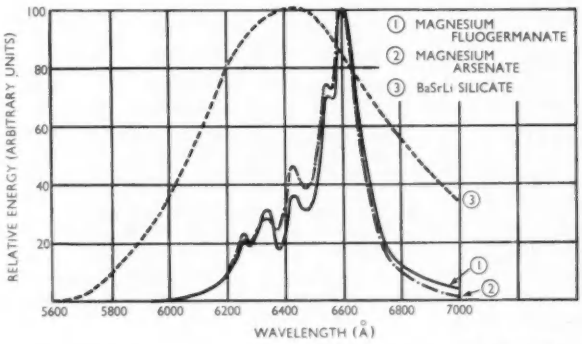


Fig. 3.—Emission spectra of red phosphors beyond 5,600 Å.

(fig. 1). Higher red ratios have, in fact, been obtained experimentally but, as will be explained later, the effect of the body colour of these phosphors tends to vitiate the higher red values obtained.

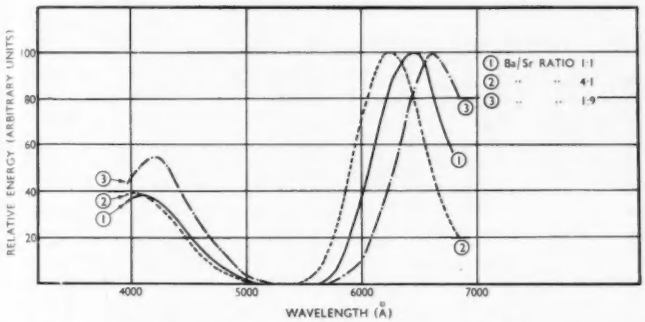


Fig. 4.—Effect of composition of matrix on the emission characteristics of BaSrLi Silicate phosphors.

(b) Emission Spectra.

The emission spectra of these new red phosphors are shown in fig. 3. The arsenate and fluogermanate show banded structure with well-defined maxima, occurring at approximately 6,260, 6,335, 6,425, 6,535 and 6,600Å. The nature of this type of structure has been attributed by Kröger[7] to the effect of tetravalent manganese atoms incorporated in the lattice.

The spectra of barium strontium lithium silicate phosphors activated with cerium and manganese consist of two broad structureless bands. The shorter wavelength band is due to cerium, while the orange or red band is due to the manganese activator. The blue band is reduced in intensity as the concentration of manganese is increased. The change in position of these bands with changes in the barium and strontium ratio in the matrix is shown in fig. 4.

(c) Temperature Characteristics.

The effect of temperature on the fluorescence of the new red phosphors is shown in fig. 5. It will be seen that the light output is maintained up to a temperature of about 300 deg. C. and that each substance reaches a maximum at about 150 deg. C. The emission bands of the three phosphors are displaced at higher temperatures towards the yellow. This effect, which is most marked with the silicate phosphors, accounts, at least partially, for the gain in efficiency at higher temperatures.

6. NEW H.P.M.V. FLUORESCENT LAMPS.

The chief factors which determine the performance of the new H.P.M.V. fluorescent lamps are discussed below. Only lamps of the quartz inner type have been considered but work on high ultra-violet transmitting glasses suggests that glass lamps, particularly for 250 watt and 400 watt ratings, may be developed.

(a) The Fluorescent Coating

Magnesium arsenate and fluogermanate phosphors may be applied to the outer bulb by the nitrocellulose binder technique used in coating tubular fluorescent lamps. The nitrocellulose binder is subsequently removed by baking at about 500 deg. C. in air. This method cannot readily be used for the new silicate phosphors due to oxidation of the trivalent cerium activator under these conditions with a consequent depreciation in the phosphor efficiency. The method which has been used successfully comprises dusting or spraying the dry powder on to a dilute phosphoric acid film on the walls of the bulb. The coated bulb is subsequently baked at about 300 deg. C. in an inert atmosphere.

The optimum coating thickness depends, among other things, on the particle size of the

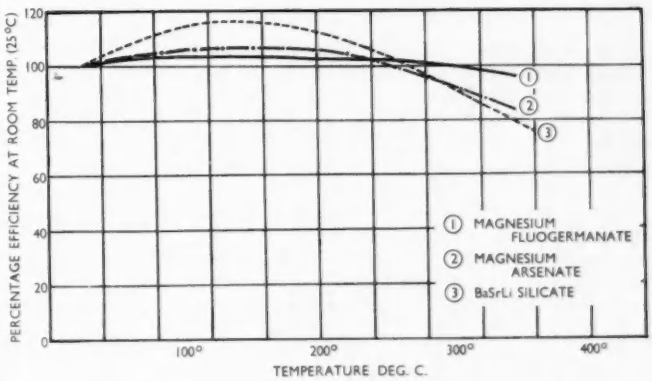


Fig. 5.—Temperature characteristics of red phosphors.

phosphor and its body colour. It is desirable to have the coating density high enough to absorb all the ultra-violet radiation from the discharge tube and yet not high enough to cause serious loss of discharge or fluorescent light by absorption. With the arsenate and germanate phosphors by the desire to achieve the same dimensions as a 150 watt G.L.S. lamp and other considerations. This gives a bulb operating temperature of about 150 deg. C. which is entirely suitable for the new red phosphors as will be seen from the temperature response curves in fig. 5.

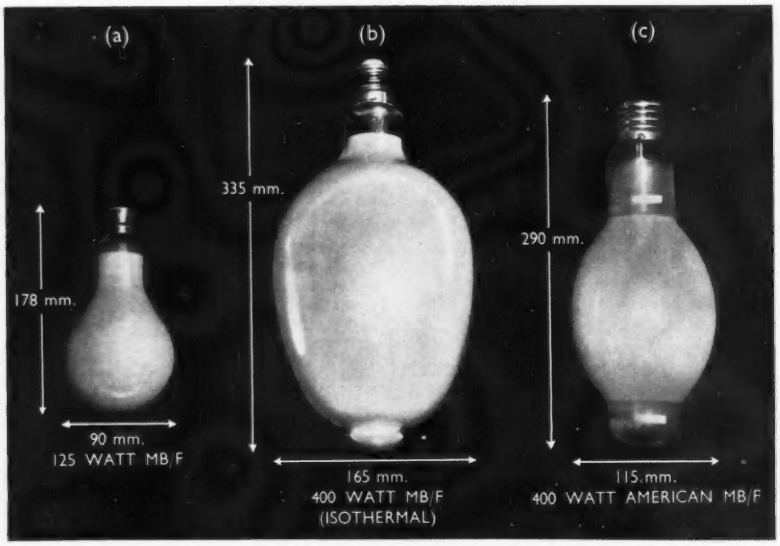


Fig. 6.—H.P.M.V. fluorescent bulbs.

high coating density enhances the green colour of the light due to their visible absorption bands and for this reason a red correction less than is possible from these phosphors has to be accepted. In practice coating densities of the order of 3 mgm. per cm.^{2} of bulb surface are used for all three phosphors.

(b) Effect of Gas Filling in Outer Bulb.

The advantage of an oxidising atmosphere such as carbon dioxide in the outer bulb to improve the lumen maintenance performance of magnesium arsenate phosphors has been described.[8] It has been suggested that the action of the carbon dioxide is to keep the manganese activator in the tetravalent state.[8] A similar advantage has been found in using carbon dioxide with the new red silicate phosphors, but the same explanation of its action cannot be applied to these phosphors, in which the manganese is almost certainly present in the divalent form.

(c) Bulb Size and Choice of Phosphor.

The bulb of the uncorrected 125 watt lamp is 90 mm. in diameter and this size is determined

In the United States, 400 watt lamps using a germanate phosphor have been marketed,[9] in which an ellipsoidal bulb is used (fig. 6(c)). The operating temperature at the point of maximum diameter is about 250 deg. C. when the lamp is burnt vertically. Experimental 400 watt lamps have been made in England with the new silicate phosphors using the isothermal bulb shown in fig. 6(b). The operating bulb wall temperature is about 170 deg. C., which is not too high for the silicate phosphors.

While illuminating engineers will, undoubtedly, frequently prefer as small a bulb as possible, it should be noted that the best luminous performance from the quartz lamp itself is not likely to be obtained if the bulb wall temperature much exceeds 250 deg. C. Additional losses due to internal scattering and absorption will also tend to increase with smaller bulb size. These considerations make it desirable to use bulb sizes larger than the phosphor characteristics would suggest as reasonable.

For lamp ratings of the order of a kilowatt or greater there seems little doubt that only the

most temperature stable phosphors may be used if the bulb size is to be kept to something reasonable. Experimental 1 kW fluorescent lamps coated with magnesium arsenate or fluogermanate phosphors will operate satisfactorily in the isothermal bulb shown in fig. 6(b) in which the bulb wall temperature is approximately 300 deg. C. This temperature is, of course, too high for the silicate phosphor.

Apart from the matters discussed above which affect the choice of phosphor, there is the question of colour rendering and colour appearance referred to in an earlier section. There is also the important question of the cost of the phosphor. There is little to choose between the silicate and arsenate phosphors on the score of cost, but an estimate based on the present world price of germanium gives a figure for the germanate phosphor of about four times that of the other two. This may militate against its widespread use despite its excellent performance at elevated temperatures.

7. COLORIMETRIC AND PHOTOMETRIC PERFORMANCE OF NEW H.P.M.V. FLUORESCENT LAMPS.

It has been the practice in England to express the red content of H.P.M.V. fluorescent lamps in terms of the luminous flux passing through a Wratten No. 25 filter. This, expressed as a percentage of the total lumens from the lamp, is known as the red ratio. The method is convenient and is a reasonable method of assessment provided only one type of phosphor is in question. The weakness of the method is that it does not distinguish between red radiation in the upper and lower wavelength regions of the band transmitted by the filter. It has been used for lamps with the new phosphors because the emission of these covers substantially the same wavelength band, but red ratios for sulphide phosphors, for example, should not be compared with those for the new phosphors.

Another defect in the red ratio method of assessing colour-rendering quality is that it does not tell what is happening in the blue or green regions of the spectrum. This is particularly important in the new lamps where one phosphor may have a high red emission but, because of its body colour, may reduce the blue content of the light and increase the green.

It would seem, therefore, that the method of measuring luminance in spectral bands described by Winch,[10] or a simplified version of it, is likely to find use with these new lamps. The measurement of the colour appearance in terms of C.I.E. trichromatic coefficient presents no difficulty and is likely to come into general use for the new lamps.

Table 3 gives the spectral band measurement for a few lamps coated with the new phosphors. It will be noted that the significant differences arise in the blue bands 2 and 3 and the red band 7. In the former the silicate lamp is higher, while in the latter the germanate and arsenate lamps are higher. This is further brought out in the colour appearance chart shown in fig. 7 in which the co-ordinates for the silicate-coated lamp lie close to the black body locus.

The luminous efficiency and lumen maintenance of the new fluorescent lamps follow fairly closely that of the lamp without the fluorescent

TABLE 3.

LUMINANCE IN SPECTRAL BANDS.

H.P.M.V. Lamp and Coating	1 4,000-4,200Å	2 4,200-4,400Å	3 4,400-4,600Å	4 4,600-5,100Å	5 5,100-5,600Å	6 5,600-6,100Å	7 6,100-6,600Å	8 6,600-7,200Å
125 watt; uncoated lamp ...	0·019	0·73	0·10	1·18	52·1	44·2	1·35	0·29
125 watt; magnesium arsenate coating	0·013	0·53	0·09	1·2	49·6	41·2	6·6	0·79
125 watt; silicate coating ...	0·016	0·61	0·12	1·1	48·2	44·7	5·0	0·30
400 watt; magnesium fluogermanate coating	0·011	0·40	0·05	0·82	44·4	47·8	5·8	0·75

coating, provided the lamp coating is correctly processed.

8. CONCLUSION.

It is, perhaps, not too much to claim that the new H.P.M.V. fluorescent lamps compare in colour-rendering quality with high efficiency tubular fluorescent lamps developed for commercial and industrial lighting. In wattage ratings below 150 watts the luminous efficiency of the new lamp is about 25 per cent less than that of the 4 ft. 40 watt tubular fluorescent lamp of equivalent colour but this difference is much less in 400 watt and higher wattage ratings.

When these new lamps become generally available the illuminating engineer will have at his disposal a range of high efficiency, high lumen output discharge lamps having colour characteristics suitable for many forms of commercial, industrial and street lighting. In lighting applications where still better colour rendering is required, as in shop window lighting for example, the present practice of adding tungsten light to the H.P.M.V. discharge light will undoubtedly continue. The proportion of tungsten to discharge wattage required to produce a given colour-rendering effect will be lower with the new lamps with a corresponding increase in the overall luminous efficiency of the system.

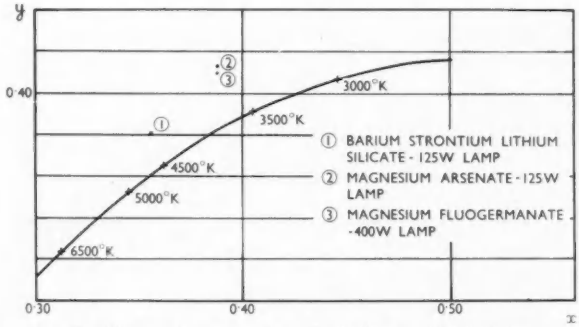


Fig. 7.—Chromaticity co-ordinates of 125 watt H.P.M.V. lamps with various coatings.

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Modern Developments in D.C. Crane Control Gear

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Fig. 1.—Two 110-ton D.C. travelling cranes in the Heavy Engineering Works at Witton.

The author discusses the problems which face the designer of electrical equipment for overhead travelling cranes and explains how these are usually best met by using a D.C. supply and series wound driving motors. The advantages of this type of motor, particularly for hoisting drives, the methods of affording precise control and the importance of proper safety devices are dealt with fully. Recommendations are made as to the most suitable type of equipment to meet the exacting requirements of industry in these days of ever-increasing demands for maximum production.

THE increasing size of modern machinery, bringing with it components both heavy and awkward to assemble by hand, together with the need for greater production, call ever more insistently for the necessary crane facilities to assist such production. Many components, and often large machines, demand precise lifting and lowering, and for this class

of work the D.C.-operated crane has advantages which have not yet been equalled by those using alternating current.

The provision of a D.C. supply for such purposes in a Works of reasonable size is a comparatively simple matter, and when the advantages of D.C. operation are fully assessed, such provision is seen to be well justified.

The development of the D.C. motor for drives involving high starting torques, high acceleration rates, a wide range of speed control and dynamic braking to give quick stopping and reversing, has focused the designer's attention upon what were once considered its weaker points. Improvement in these respects has now made the D.C. motor, and particularly the series machine, virtually as reliable as the A.C. induction motor, with the added advantages of greater flexibility in application. The use of the series wound motor is practically standard practice for D.C.-operated cranes, where full advantage can be taken of the desirable features already mentioned in obtaining the best handling facilities from such cranes.

TRAVEL MOTIONS.

The travel motions of an overhead travelling crane, both for the cross travel (along the crane bridge) and that of the crane bridge along the building, do not in general call for such refinement as the hoisting motion, but a few notes on the control of these motions will no doubt prove useful. The normal series starting resistance, suitably rated, will generally provide sufficient speed control of the motor for all ordinary purposes. If it is important that there shall be no great rise in speed as soon as the bridge or the crab is moving, particularly on light loads, provision can be made for this by connecting a diverter or shunting resistance across the motor armature on the first or second notches of the controller. This not only increases the field current but also keeps at a low value the voltage impressed on the armature and thus prevents any great rise in speed. It also has a braking effect if the operator is slowing the crane down preparatory to stopping. Under these conditions the motor acts as a generator, the resistances across the armature taking current from it, and the kinetic energy of the moving parts is absorbed by the generated load.

Some crane engineers have at times expressed dissatisfaction with the series motor, because the travelling speeds were appreciably higher than those calculated, there was a lack of speed control on the earlier control notches, and on the final one a speed which was inconveniently, or even dangerously, high particularly where the crane was controlled from the shop floor by pendant cords. These symptoms indicate at once that the motor for that particular travel motion is too large, and is very probably being loaded to the extent of only 60 per cent of its normal output when travelling the crane with full load on the hook. The writer has come across many such cases.

It should be remembered that even short-time rated motors are designed on a basis of dealing successfully with an overload of 100 per cent for 30 seconds, which is quite an appreciable period on crane motions. Unless the friction allowances have been computed on a very optimistic basis, and the crane and its tracks very poorly erected, an overload in torque of more than 30 to 50 per cent is extremely unlikely, and that for only very short periods, say, a few seconds. A motor which was fully loaded on the ordinary portions of the track would take the above overloads quite easily unless the controller were on such a notch that not more than full-load current could pass to a stationary motor. It is also quite common to receive orders for controllers for the travel motions which specify 100 per cent full-load current on the first step, or notch, for a motor that has much more than adequate provision for the duty, and which calls for very slow speeds on the first one or two positions of the controller. If the horse-power of the motor has been correctly estimated, a resistance passing 100 per cent full-load current will mean that the motor will be doing little more than just turning over on the first notch. Many cases have occurred where a controller has been held on first notch and the motor has accelerated up to 40 per cent of normal speed and on the second point to 70 per cent using standard resistance proportions. Where slow speeds of the order of 20 per cent with partial load are required, it is better for the crane maker to give the size of motor it is proposed to fit, the total weight of crane or crab and the load to be handled, running speed on the basis of normal full-load speed of the motor, an idea of the speed required on the first one or two notches, and to leave the actual value of current passed and resistance to the controller maker. Another method of preventing the possibility of over-speed, covered by the overhead crane specifications of the American Association of Iron and Steel Electrical Engineers, is as follows :

The horsepower of the travel motors is fixed by certain factors for friction and acceleration. For an acceleration of 1 ft. per sec. per sec., which is ample for normal crane service, these factors come out at 48 lb. per ton of the combined weight of bridge or crab and load. When

the gear ratio for the travelling speed is being calculated, however, the horsepower of the motor has to be based only on the friction factor, of approximately 27 lb. per ton, and its speed for this output used in finding the gear ratio.

This will definitely prevent serious over-speeding due to the motor's being only partly loaded, as most of the rise due to reduction of load will have been allowed for. At the same time, owing to the increased gear ratio, acceleration up to the running speed, represented by the full-load speed of the motor, will be brisk. The above figures are for sleeve bearings; for ball and roller bearings the figures are 38 and 17 lb. per ton respectively.

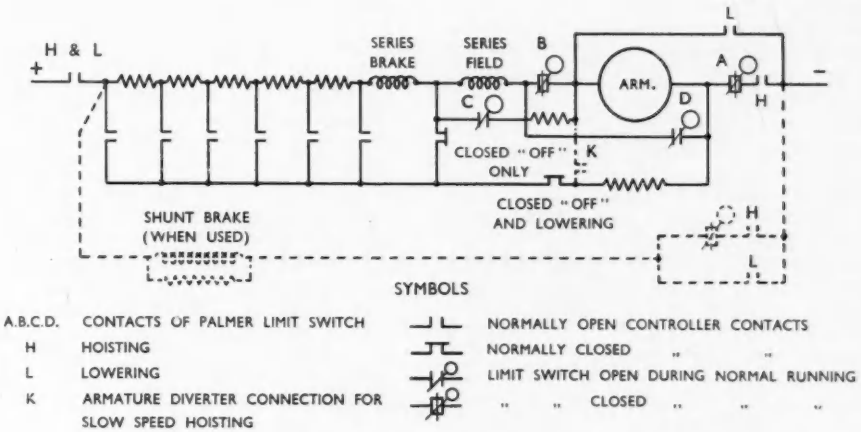

Fig. 2.—Diagrammatic arrangement of the hoisting circuit for a large travelling crane.

HOIST MOTION.

It is on the hoist motion, however, that the use of D.C. for the power supply is really justified, if it is of any importance to be able to lower a heavy load slowly and carefully. A further advantage of the D.C. series motor for a busy crane with a considerable height of lift is that, for partial loads, there is an appreciable rise in speed. The loads on most cranes are generally a good deal less than the full load, so that there is a big saving in time of handling such partial loads due to the rise in motor speed, and although, when driving down the empty hook, the rise in speed is considerably less, a useful increase in motor speed can be obtained over the normal figure; at the same time the motor is always under full control.

When hoisting, series control is the usual scheme employed with a series motor, since there is always some load on the motor even with an empty hook; when lowering, what is generally referred to as potentiometer control is used. This is also referred to as dynamic braking control because the motor is so connected that when a load is being lowered and is tending to drive the motor, it can generate round a closed circuit in such a manner as to dissipate the energy of the falling load as heat in a resistance.

A simplified, or schematic, diagram of series hoisting and potentiometer lowering control for a crane motor is shown in fig. 2, and such control will now be described with reference to this diagram.

To begin with the hoisting circuit will be described. On the first position of the control switch the motor is connected with the starting resistance and brake coil in a simple series circuit, the resistance being such that about 70 per cent of full-load current flows. This is sufficient to lift the brake magnet and release the brake, which is nowadays almost invariably on the motor or first motion shaft, and to produce sufficient motor torque to start and lift approximately half-load. This does not mean that any load above half-load will run down, because as bearing friction and gearing losses have now to be supplied from the potential energy of the load itself, it will take approximately another 25 per cent of load to supply these, and only with a weight in excess of 75 per cent load will there be sufficient torque from the hook load to turn the motor in opposition to the drive and let the load run down. On the other hand, although the motor speed with an

empty hook will probably rise to about its normal full-load speed, or even slightly over, without the controller's being moved to a later notch, such rise in speed will be fairly slow, thus enabling the operator to take up slack, and get a taut rope to pick up a standing load without snatch. Should it be required to hoist an empty hook, or a very small load, at a creeping speed, then the dotted connection marked *K* should be arranged to close on the first, and if necessary second, hoisting position. This increases the field current, which of itself tends to reduce motor speed, and at the same time by increasing the voltage drop across the starting resistance, brake coil and field, reduces armature voltage and therefore speed. The effect of this arrangement in preventing a rise in speed with an empty hook can be seen from the fact that, while with the ordinary series resistance limiting the starting current to about 70 per cent of full load, the empty hook speed of the crane would probably reach 80 to 90 per cent of normal full load, the connection of a suitable diverter resistance would limit this speed to about 12½ per cent of normal, and reduce starting torque by only 20 per cent below that developed without the diverter.

The control of the acceleration up to full speed varies somewhat according to the size and duty of the crane. For small and medium horsepowers and ordinary crane duties, this can generally be left completely to the crane driver, but for the larger horsepowers, and particularly for busy cranes, automatic control is advisable.

If acceleration is to be left to the crane driver, standard-type drum controllers are usually quite satisfactory. Most modern ones handle currents of the order of 50 to 60 amp. quite well, even when operated as often as fifty times an hour.

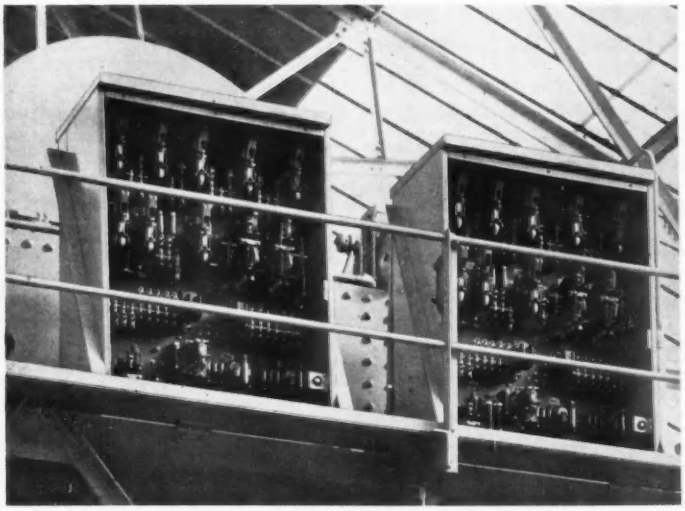

Fig. 3.—Contactor panels for controlling the 60 h.p. main hoist motor and 45 h.p. auxiliary hoist motor of a 110-ton D.C. travelling crane.

When currents rise above this value and operation is more frequent, the size of drum controller necessary added to the more frequent operation, can cause appreciable fatigue to the operator. Contactor-type control panels and a small master switch obviate this, but because it is so easy for the operator to go to the full-speed position right from the start, and because of the larger equipments usually dealt with, it is essential that some form of control, independent of the operator, should be provided to govern the rate at which full speed is attained.

In the past this has generally been achieved by using a feature which may take the form of either a current limit relay or of current lockout contactors, which prevent a further step of resistance being cut out until the current has fallen to approximately full load. At first sight this seems sound enough, but in practice it has the following disadvantages.

(1) On light loads, and particularly if adjusted to take care of some of the other points mentioned below, current peaks are not

high enough to cause the relays or lockouts to function until the last point has been reached, and a very high rate of acceleration is attained which may cause serious inconvenience and sometimes dangerous " snatching " if a fair amount of slack rope has been paid out from the crane drum.

(2) A margin has to be left on the operation of the current limit relay or lockout to cover low voltage periods, which means that at times of normal or slightly high voltages, there is a marked tendency for the high acceleration mentioned in (1) above to occur. A similar margin should also be left to cover the occasional small overload that in itself is well within the crane's capacity. If this is not done, there is a strong probability that some sections of the resistance will be left in circuit when they should have been shorted out, and in consequence become overheated or even burnt out. The usual proportions for starting resistance generally make it necessary for the first step of resistance to be cut out in order to start with full load on the hook and adjustment of the current relay or lockout to a value slightly on the low side may actually prevent the crane's handling its full load.

Modern practice is to replace the current limit by a device affording a definite time interval, generally one in which it is possible for a reasonable amount of adjustment to be made easily at the time of installation. There is no necessity for this feature on every step of resistance, because, as mentioned above, it is not usual to require the full load to be lifted on the first control point. Therefore, provided that the crane operator can remain on this point when necessary for the slow hoisting of a light load, there is no practical objection to allowing him the option of going directly to the second control point, at which he will get sufficient current to start with full load on the hook. So far as the motor is concerned, starting currents up to two or even two-and-a-half times full load can be handled quite satisfactorily by the modern series motor. A definite time lag of approximately one second per step is adequate for the remaining steps of acceleration, and while the motor will accelerate rather faster with a light load or empty hook, sufficient control is retained to prevent " snatching ". It also gives time for the motor to gain enough speed between steps to prevent the current peaks, which occur when sections of resistance are cut out, from being above those which the motor can handle quite easily, even with normal overloads on the crane hook. If the overload is above that which the motor and crane should handle, it prevents the operator trying to do the impossible and thereby overheating the resistance, because the definite time lag ensures that within a few seconds the current value will have risen to a figure at which the overload protection functions, cuts off the supply and allows the resistances to cool down, and also protects the motor. It should be noted that in the diagram (fig. 2) the sequence of operation of the time-lagged contactors for the hoisting circuit is from left to right, and that once a contactor has operated it remains closed unless it is desired to reduce speed, and that no time lag is necessary when the contactors are opening. On the lowering circuit they close in the reverse order, *i.e.* from right to left. A time lag between the operation

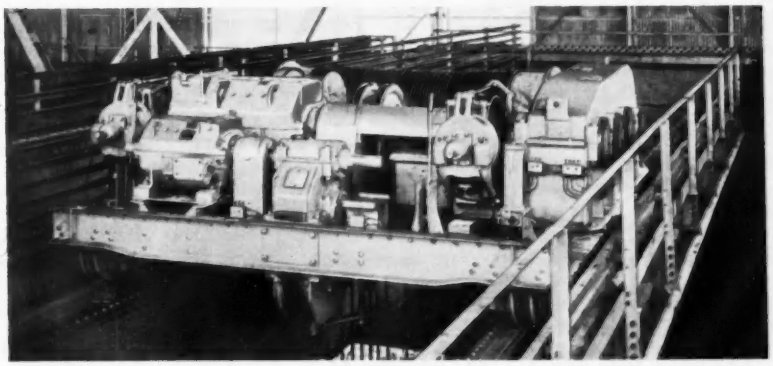

Fig. 4.—50 h.p. and 100 h.p. series wound motors for the traverse and hoist of a 135-ton crane in the Abbey Works of the Steel Company of Wales.

of each is necessary, though it can be shorter than for hoisting, but when slowing down, these contactors operate in the same sequence as for speeding up in hoisting, and a time lag of similar order is required. Furthermore, when lowering, only one contactor remains closed at a time for steady speed conditions, the preceding contactor in the sequence of operations dropping out as soon as the following one has closed. It is also essential that the one which is to close, does so and makes circuit before the one which is to open has opened its contacts, so that there is practically no risk of the armature circuit not being maintained. If the armature circuit should open when there is enough load on the hook to overhaul the gears there would be no limit to the speed attained by the armature and a dangerous speed could be reached in a very short time. If a drum controller is used for handling the mains current, overlap of the contacts is easily arranged by the maker and proper servicing should maintain this feature. But the crane operator should be instructed that, although there is no objection to his returning the control handle from top speed to a lower speed position without pausing when hoisting, lowering should always be done notch by notch with a short pause on each one. Neglect of this rule, when the hook is anywhere near fully laden, and especially if the motor has had time on the higher speed position to attain its full speed for that point, can result in a "flashing over" across the brushes and commutator.

The hoisting circuit cannot be left without reference to brakes and limit switches, as these items and their correct positioning in the circuit can greatly affect the safety of operations. The type of brake will be dealt with first, as this also affects the type of limit switch to be used.

BRAKE MAGNETS.

The series brake magnet is most commonly used and, in the writer's opinion, provided the coil is placed where shown in the simplified diagram, there can be no argument against it or in favour of the shunt brake magnet, other than the fact that the shunt magnet is a little smaller and cheaper, but this is more than offset by the other economies consequent upon the use of a series wound magnet.

The advantages of the series magnet are as follows :

(1) It is generally faster in operation due to its lower inductance, both when releasing the brake and when the brake is setting.

(2) Its use saves one trolley wire on the bridge and the auxiliary point on the limit switch.

(3) A little less wiring and the absence of the extra contacts on the controller.

(4) No risk of high induced voltages when the coil circuit is broken. This can be reduced with the shunt magnet by the use of a discharge resistance (the resistance to be really effective must be mounted on the crane crab and connected solidly across the coil), but tends to cause sluggish operation in the brake at all times, particularly when the crane is stopped by the limit switch, when rapid brake operation is most important.

It is asserted by some crane makers that the use of a series magnet with potentiometer control on the lowering side causes the brake to come on and off when there is sufficient load on the hook to overhaul motor and gears. This can happen if the coil is connected between the common line contact for both hoisting and lowering and the first point of the main series resistances. The writer has seen crane diagrams where this has been done under the mistaken impression that it was safer for the series brake coil to be outside the armature loop circuit. In this position, when lowering a load capable of generating sufficient current to supply the field current of the motor at the last or full speed lowering position, no current will circulate in the brake coil which therefore releases and causes the brake to set. The motor now makes a demand on the line for current to supply the torque, so the brake releases again; the current demand by the motor then ceases and the brake again sets. When connected as shown in the diagram, however, it does not matter whether the current in the coil is from the line or generated by the motor due to an overhauling load, the brake will be maintained in the released position until the controller is brought to the "off" position which breaks the line circuit and leaves the brake coil outside the armature loop, so that the brake sets immediately.

LIMIT SWITCHES.

Limit switches are used to cut off the supply to the motor and brake should the operator, for some reason, fail to do so at the proper time on the controller. It is usual to fit limit switches for the hoisting direction only. Unless the crane has to be used very close to the overhead structure, a single pole series limit switch is usually all that is necessary when a series brake magnet is used and connected at *A* in the diagram. It should be capable of breaking about $1\frac{1}{2}$ times the full load current of the motor at full line volts in case the operator has stopped the crane just below the normal operating point of the limit

switch and then restarts, so that the switch is operated while the motor is accelerating and taking more than its normal full-load current. As the hoisting circuit is a plain series one, cutting off the supply to the motor also cuts off the supply to the brake magnet, and there is no loop circuit across the armature by which its generated current prior to stopping can hold off the brake. Cranes are occasionally seen with shunt brake magnets on which a single pole series limit, as described above, is relied upon, and with the shunt coil connections so made that this limit switch does disconnect it from the line. It is, however, left so that the coil is shunted across the armature and in these circumstances the brake will not set until the armature has reached a very small proportion of its normal speed. If the crane is hoisting the empty hook only, the motor speed will probably be about double the normal, and the only load tending to bring it to rest will be the friction in the gearing and the weight of the bottom block, both of which are small, and, under these conditions, the overrun distance after the limit switch has operated can be easily five times that obtained with either a series brake or a limit switch having an extra point to open the brake coil circuit. Very few cranes have enough safe overrun to allow this, and therefore the extra limit switch point for the shunt brake magnet, shown dotted on the diagram, and the extra controller contacts associated with it are essential for safe use of the shunt magnet.

It must be realised that the danger here is due to the fact that although the supply to the motor has been discontinued, very little has been done to absorb the kinetic energy of the revolving armature, which is considerable due to its high speed. If the brake is not applied for this purpose, it has to be done very suddenly through the crane rope when the bottom block is wound into the overhead gear. The very short distance in which the motor has now to stop means that the strain in the rope may reach breaking point, and the bottom block may be dropped with possibly fatal results.

Frequently the amount of safe overrun which can be provided is very limited, it being necessary to be able to run the hook with a full load on it very close to the overhead gear, and yet it is still necessary to prevent the bottom block from fouling even when the empty hook is run up at maximum speed and the crane is stopped by the limit switch. A special type of limit switch, generally known in this country as the Palmer limit switch and in the United States as the Youngstown type, is a very great help in dealing with this problem of quick stopping, as it provides dynamic braking to assist the mechanical brake. It comprises a switch having two sets of normally closed contacts during normal running, and two sets of normally open contacts which close immediately after the normally closed ones have opened. *A* and *B* on the diagram represent the normally closed contacts, *C* and *D* those normally open. *A* is the ordinary single pole opening point which is also common to the normal limit switch. *B* is another single-pole switch which disconnects the armature from the series field so that this field can be reconnected to the armature through the contacts *C* and *D* in such a way that the generated current flows through the field in the right direction to preserve the same polarity as when the field was excited from the line. A resistance connected between *C* and one side of the armature limits the current generated to a safe value, and the whole arrangement provides powerful dynamic braking, very rapidly absorbing most of the kinetic energy of the armature. It will be seen that the circuit of the series brake magnet is also interrupted so that it will set at once and thus the armature can be brought to rest in the minimum possible distance of overrun. The value of the device resides in the fact that the higher the motor speed at the time the limit switch operates, the more severe is the dynamic braking, thus providing some measure of equalisation of the overrun distance as between full load and empty hook. The Palmer-type switch, as made, does not have any provision for use with a shunt brake, but in any event the shunt brake is at a disadvantage compared with the series brake in the matter of quick stopping.

Power Network Control and Protection by Modern Communication Techniques

By L. I. FARREN, M.B.E., M.I.E.E., Whitworth Scholar, A.C.G.I., D.I.C.
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The interconnection and integration of large power generation and distribution networks depend nowadays, for efficient operation, on the employment of communication systems linking the various units of the power network. This article describes the range of facilities provided for this purpose, including telephony, apparatus for supervisory control and indication, telemetering, intertripping and high-speed protection; special communication cables are also provided and equipment for transmitting signals over the actual power lines.

INTRODUCTION.

COMMUNICATION techniques are finding an increasing use in the control and protection of large power generation and distribution networks. The range of facilities provided for this purpose includes telephone equipment, apparatus for supervisory control and indication, telemetering, intertripping and high-speed protection, special communication cables which may be suspended from the power line towers and equipment for transmitting signals over the power lines themselves.

1. THE POWER NETWORK.

To begin with, it will be helpful to consider, in broad terms, the type of system with which this article is concerned.

The power supply will come from a number of generating stations, possibly both steam and hydro, and possibly separated from one another by considerable distances depending on the availability of fuel or water power or on the load requirements of particular areas.

The system may relate to an area as small as a county or as large as a whole country. The generating stations will be linked to one another and to major distribution substations by an overhead E.H.T. network, and possibly connected to similar adjacent networks by feeders at the same or higher voltage. These generating stations and major substations will usually supply the urban area immediately surrounding them at voltages down to the consumer's voltage mainly by underground cable, and the rural areas beyond by overhead networks.

At some convenient point there will be a central control room or load despatching office (L.D.O.) from which control is exercised over generation and E.H.T. distribution.

Each generating station will have its own control room from which the station is controlled to the instructions of the central control; the same control room or possibly a separate room is used to control the local urban and rural networks.

2. SERVICES TO BE PROVIDED.

These are outlined below but will be described more fully later in the article.

(*a*) TELEPHONY.

To secure efficient operation it is desirable that every point in the network which is normally staffed should have telephone service. Likewise, those points which are staffed only at time of trouble should also be provided with a telephone.

In Great Britain, telephone services are provided both for the Divisions and the Area Boards by the Post Office, by private lines and by power line carrier systems. In special cases, as for example when maintenance and construction work is taking place at some remote point, VHF radio systems are employed.

(*b*) SUPERVISORY CONTROL AND INDICATION.

Any plant which can be arranged to be operated electrically can be remotely controlled, and the function of any system of supervisory control is to enable a number of items of equipment to be

controlled from a remote point over one or more communication channels.

Similarly the indication of the position or condition of items of plant (circuit breakers, transformer tappings, etc.) may be provided at the remote point over the same or other communication channels.

(c) TELEMETERING.

In most supervisory control systems the provision at the central station of meter indications of various electrical quantities at the remote station is essential for efficient control.

(d) CARRIER CURRENT PROTECTION.

The growth of E.H.T. transmission systems interconnecting large sources of electrical power has led to the demand for rapid clearance of faults in order to preserve system stability. By the use of carrier frequency currents over the power lines themselves, a system has been developed jointly by A. Reyrolle & Co., Ltd. and The General Electric Co., Ltd. which provides high-speed protection with a high stability factor. The system is known as the Reyrolle/G.E.C. Telephase Carrier Current Protection.

(e) INTERTRIPPING.

In some E.H.T. feeders, one end may be terminated in a step-down transformer to an H.T. line. For purposes of economy an E.H.T. switch is sometimes not fitted at the transformer station and the H.T. breaker is relied upon to clear this end of the feeder if faults develop. It is possible, however, for a fault to develop in the step-down transformer of such a nature that the H.T. breaker might trip at once, but for some delay to occur before the distant E.H.T. breaker trips; thus power may still flow from the distant end into the faulty transformer.

To prevent this, an intertripping system is provided between the two ends *A* and *B* such that when the H.T. breaker trips at *B* a distinctive, selective signal is sent to *A* to trip the E.H.T. breaker at that end. Also, dependent on the power transmission network, it may be necessary to trip the H.T. breaker at *B* if the E.H.T. breaker at *A* trips due to a feeder fault.

(f) TELEGRAPHY BY TELEPRINTER.

The value of the teleprinter in power system control is becoming more generally realised with its increasing use. Its main advantage over the telephone is the production of a printed record of all orders passed.

Apart from its use for sending orders it may also be used for the routine transmission of meter readings back to the control station.

3. COMMUNICATION FACILITIES.

The types of circuit over which signals may normally be transmitted, to provide the facilities outlined above, are as follows:

(a) RENTED CIRCUITS.

These may be open wire or cable circuits rented from the public telephone communication authority. The main advantage of such circuits is that no immediate capital charge to the power authority is involved, and maintenance of the circuit is the responsibility of the communication authority.

If the rented circuits are in buried cable the degree of reliability to be expected is very high; however, if a breakdown does occur in a multi-pair cable carrying rented circuits, re-establishment of all the circuits in the cable may take some time. In such an instance the power authority may be in competition with other renters of circuits in asking for priority in reconnection.

Rented circuits employing aerial lines should be avoided in areas subject to extreme weather conditions on account of the liability to interruption by damage due to lightning, gales or blizzards; this might happen just at a time when the telephone or signalling circuits are most needed.

(b) PRIVATELY OWNED CIRCUITS.

These may be buried cables, open wire lines or aerial cables. Buried cable, whether laid directly in the ground or drawn into a duct line, is certain to be expensive unless the duct line already exists, a situation which occurs rarely.

Aerial lines carried on the poles of the overhead power line have been used to a considerable extent but such circuits are subject to a number of limitations.

Owing to the relatively small size of the telephone conductors they are suitable only for short span lines. The risk of contact between the power and communication conductors exists, and often a large amount of background noise occurs in the communications circuits by induction from the power circuit.

The third choice, aerial cables, offers many attractive features and if such cables are installed when the power line is being erected the cost will be the lowest of all the private circuits, with the exception of open wire circuits on the same poles as the power lines.

The Pirelli-General Cable Works has manufactured and supplied this form of cable for the past nineteen years; the early cables were not self-supporting but had to be suspended from a separate steel catenary wire. The most modern design, known as the Telephone Earth Conductor, overcomes many of the disadvantages of the earlier suspended cable.

Suspended Aerial Cables.

Where these cables have been used they have been suspended from a separate catenary wire below the power conductors ; in general their use has been limited to medium span pole lines at 33 kV and lower voltages.

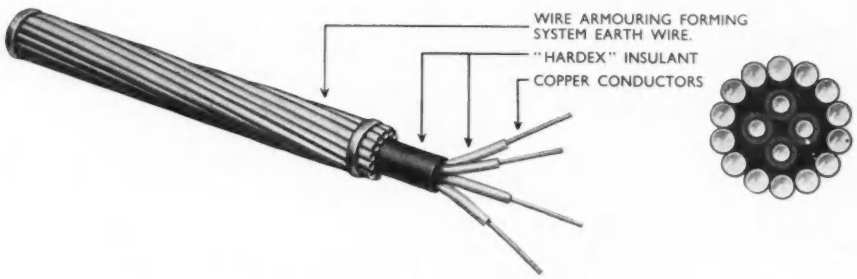

Fig. 1.—Pirelli-General telephone earth conductor.

They present a large area to snow and cross-winds causing considerable extra loading of the main power line supports. Unless the greatest care is taken to bond the lead cable sheath to the catenary wire, burning of the sheath will occur when heavy fault currents are flowing.

It is not always possible to use the power line earth wire as the catenary wire because the earth wire is often mounted above the power conductors whereas the cables, for safety, are invariably suspended below the power conductors. These disadvantages have been largely overcome in the telephone earth conductor.

Telephone Earth Conductor.

The telephone earth conductor is essentially a telephone cable, comprising one quad embedded in the centre of an earth conductor. It is self-supporting and thus dispenses with the catenary wire, and the other sheath serves as an earth conductor for the power line as well as providing mechanical protection for the telephone conductors.

Careful manufacture and balancing of the telephone conductors reduce the effect of external interference to a minimum.

The earliest cable of this kind was a four-wire, paper-insulated, lead-covered, single galvanised steel-wire armoured cable which could be used on spans of up to 400 ft., with copper power-conductors not larger than 0·1 sq. in. The telephone conductors were usually 40 lb./mile, high-conductivity copper and satisfactory speech transmission up to a distance of about 16 miles could be obtained without the need to employ loading coils. The first major improvement was to replace the lead sheath and steel-wire armour by a welded stainless-steel sheath ; the new cable was both lighter and cheaper than the old one besides being watertight and resistant to corrosion. The protection afforded by the sheath is such that even in the event of the

TABLE 1.

"HARDEX" TELEPHONE EARTH CONDUCTOR (C = ·09 μF/mile)
RECOMMENDED CIRCUITS FOR SPEECH TRANSMISSION

Length of Route (miles)	Circuit	Conductor Diameter		D.C. Resistance (ohms/loop mile)	Attenuation at 1,000 c/s (db/mile)
		In.	Mm.		
0—20	40 lb/unloaded	·050	1·27	44	0·88
20—78	40 lb/loaded 88 mH at 1·136 miles	·050	1·27	48	0·23

collapse of a support the cable would remain in service unless subjected to very severe mechanical damage on the ground.

In general, this type of cable is suitable only on relatively short span lines where a high-conductivity earth wire is not required, although additional wire armouring can be provided if desired, in which form it will be suitable for longer spans.

As a result of further development it is now possible to provide a telephone earth conductor with a non-hygroscopic plastic insulant which renders the use of a waterproof metal sheath unnecessary.

The insulant, which has been given the trade name of " Hardex," is hard but flexible, thermoplastic but unaffected by temperatures below 180 deg. F., and it has good electrical characteristics and weather-resisting properties. It is extremely light in weight and the cable is made with either single wire armouring or double wire armouring ; fig. 1 shows a section of the standard form of this cable employing a quad of telephone wires of 40 lb./mile and single wire armouring. With single wire armouring, span lengths up to 500 ft. may be used and with double wire armouring this distance may be increased to 1,000 ft.

Where heavy fault currents have to be dealt with, double wire armouring consisting of cadmium-copper wires may be employed.

This type of double wire armouring would be used in those instances where the increased conductivity of the earth conductor is considered necessary and where the reduction of tensile strength, as compared with two layers of steel wire, is not of serious consequence.

The outer diameter is 0·46 in. which is increased to 0·62 in. if double wire armouring is used.

The transmission characteristics of this cable are shown in Table 1 from which it will be seen that, subject to the circuit attenuation at 1,000 cycles/second not exceeding 18 db, a route of 20 miles may be operated if the cable is unloaded, and the route length is increased to 78 miles if loading is employed.

Aspects of interference and induction under fault conditions are considered in Section 8 of this article.

(c) Power Line Carrier Circuits.

All of the communications services already mentioned can be provided by means of carrier frequency signals transmitted over the power lines themselves.

Where the distances involved are greater than about 20 miles and especially with E.H.T. lines of 66 kV and over it is often found that power-line carrier current operation may be provided more economically than any of the alternatives.

In order to inject the carrier current signals into the power line effectively and, at the same time, to prevent the high voltages (at 50 cycles/second) on the power line from interfering with the carrier equipment, special coupling networks are employed. These have been described by W. D. Goodman[1] and J. McCulloch.[2] The connections of a typical coupling network are shown in fig. 2. The arrangement, by suitable design, may be made to provide a transmission path of reasonably uniform characteristics over a band of frequencies, for example, from 130 kc/s to 260 kc/s.

The tuned circuits L_1C_1 and L_2C_2 are arranged to resonate at the geometric mean frequency of this transmission band. The most expensive units of this coupling network are the coils L_1, which must carry the normal power line current and be capable of carrying overloads for short periods, and the capacitors C_2 which must be capable of withstanding the power-line voltage. The size and form of these components may be seen from fig. 3 ; each high-voltage

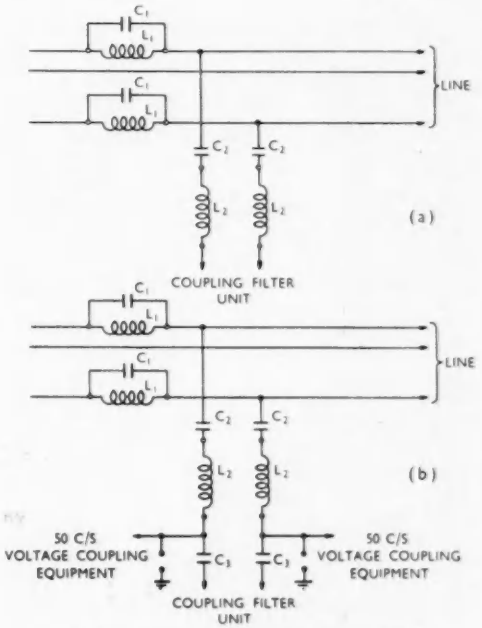

Fig. 2.—Inter-phase line coupling network.
(a) without provision for voltage couplers;
(b) with provision for voltage couplers.

coupling capacitor is mounted on a steel structure, but is insulated from the steelwork. The line-choke coil is mounted on, and connected electrically to, the top (high voltage) end of the capacitor, from which point connection is made to the power line. The top of the choke coil is connected to the station switchgear.

The components comprising the coupling filter are mounted in a weatherproof cast aluminium alloy box which is mounted between the choke-coil capacitor assemblies as shown in fig. 3.

The form taken by the line choke coils L_1, when designed for 500 amp. rating, is shown in fig. 4 in which the shroud and base cover have been removed for clearness.

The coupling equipment shown is used between phase wires and, although this is more expensive than phase-to-ground coupling, it has been adopted in Britain for the following reasons :

1. The attenuation is less at any given frequency.
2. The variation of attenuation with changing weather conditions is less.
3. The radiation of carrier frequency energy from the line is less.

Fig. 4.—Power line choke coil 500 amp. rating.

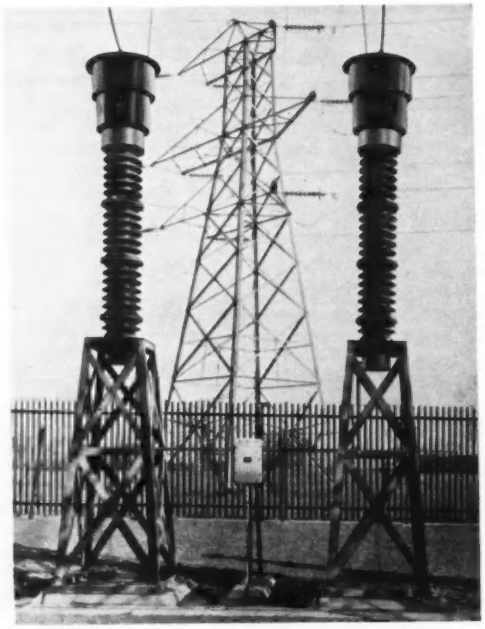

Fig. 3.—Typical line coupling equipment for power line carrier systems.

4. There is less liability to pick up radio interference.
5. A phase-to-earth fault close to the transmitting end does not result in loss of signal at the receiving end.

It is difficult to prevent carrier frequency signals on one line from appearing in other lines entering the same substation. The induction may be directly between the lines themselves or it may arise through the use of common high-voltage busbars and transformers, and through deficiencies in the line-choke units at frequencies near the edges of the transmission band, or through the presence of the third phase conductor which is not fitted with a choke coil. Cross-talk can, however, be guarded against relatively easily by planning a network as a whole and not using the same frequency more than once in any one substation.

Carrier Equipment.

The most comprehensive power-line carrier system made by G.E.C. Telephone Works is the type N power-line carrier equipment designed to provide a communication system for electricity supply authorities sufficiently flexible to cater for the requirements of today and of the future.

This system provides a maximum of eight communication circuits between the terminals.

Another system known as type P.A. provides a similar service to that given by one circuit of the type N system, and offers an economical method of communication over a power-line network when the extensibility and high circuit capacity of the larger system are not required.

Fig. 5 shows the 110 kV lines and stations of the Electricity Supply Board of Ireland and fig. 7 shows the communications network employing type N carrier equipment.

In fig. 7 the circuit numbers employed on the various power lines are indicated and it will be noted that identical numbers (and hence frequencies) are avoided on lines entering the same station.

In the type N system each of the eight communication circuits conveys an audio frequency band of 300-3,960 cycles/second which is subdivided to provide the following services :

(*a*) A duplex speech circuit in the band 300-2,700 cycles/second.

(*b*) A duplex telephone signalling channel employing a signalling tone of 3,060 cycles/second which can be used in conjunction with either manual or automatic telephone systems.

(*c*) Six super-audio duplex signalling channels, capable of operating at telegraphic speeds of 40 impulses per second (80 bauds). The frequencies employed are 3,300, 3,420, 3,540, 3,660, 3,780, 3,900 cycles/second.

These services are independent and may be operated simultaneously without mutual interference.

The method of producing the carrier frequency signals suitable for transmission over the power line is shown in fig. 6 which shows in schematic form the type N system terminal.

A complete description of this system and its mode of operation is given in the article by McCulloch.[2]

An illustration of a type N terminal is given in fig. 8 which shows the equipment at Erne on the Erne-Finglas route of the Electricity Supply Board of Ireland.

The rack assemblies employed in any system are dependent upon the facilities required and, as much of the equipment is common to a number of circuits and may even be common to more than one system, the number of racks required to equip a particular number of circuits will vary from station to station. The maximum number of racks required for a fully equipped

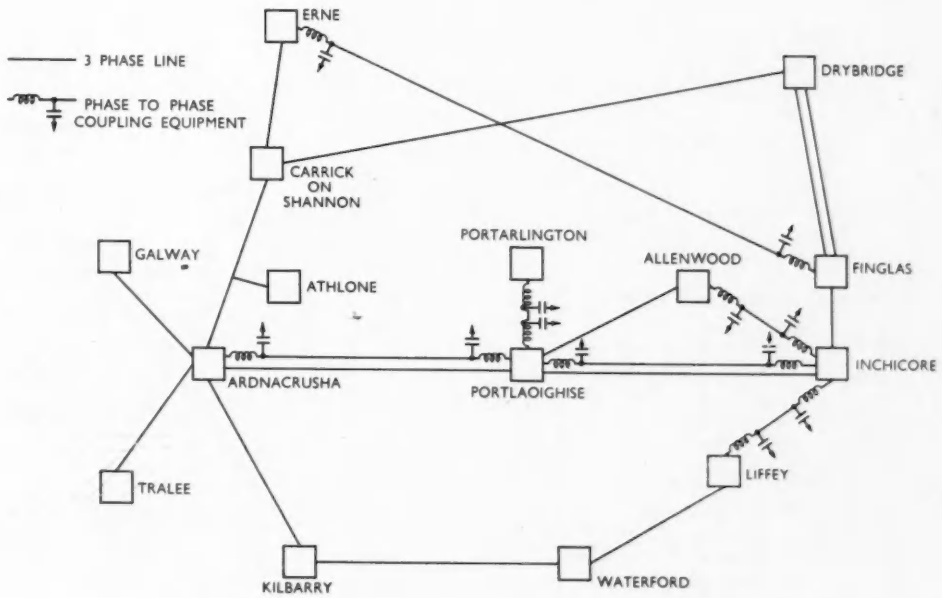

Fig. 5.—Electricity Supply Board of Ireland 110 kV lines and stations.

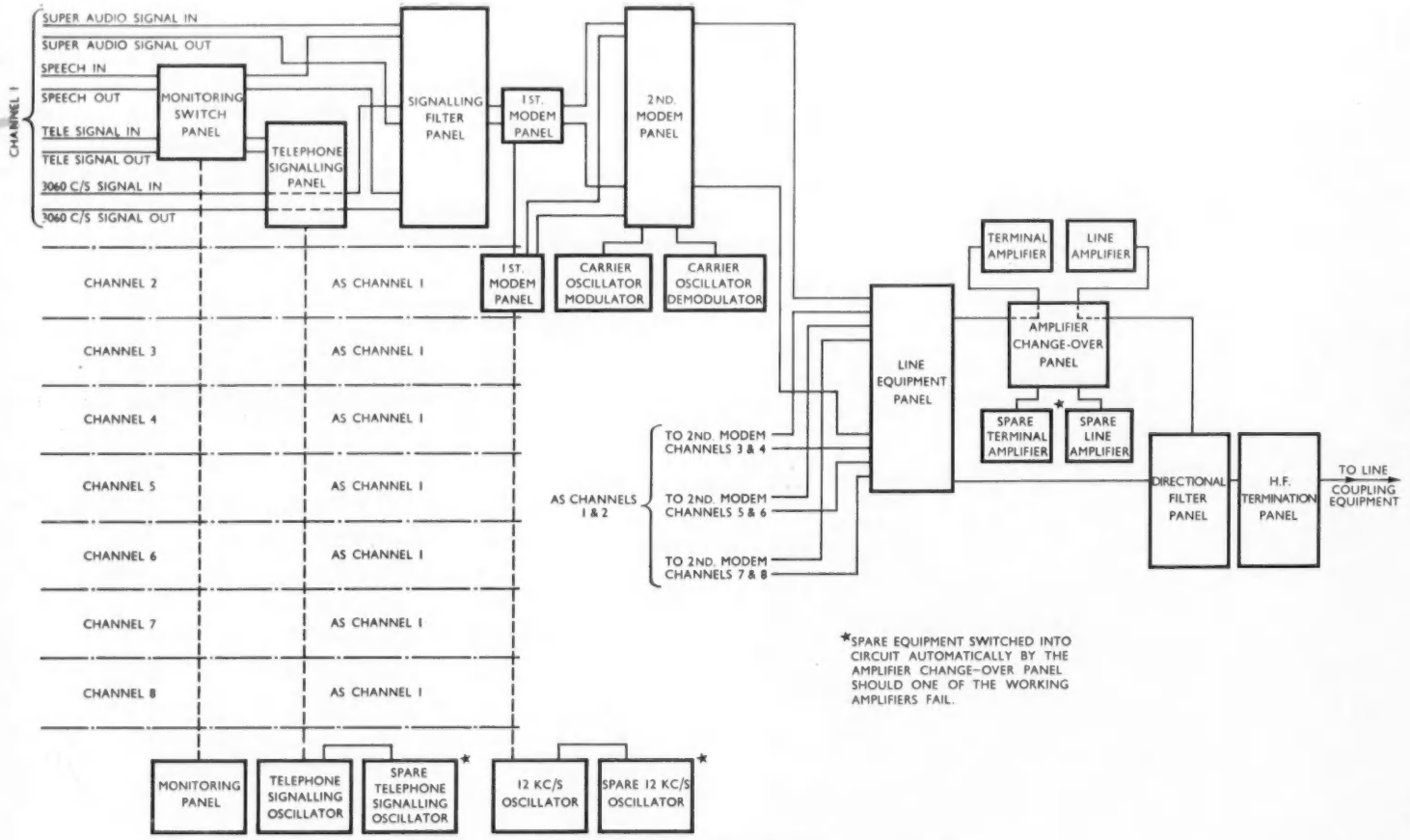

Fig. 6.—Simplified schematic of type N carrier system terminal.

system would be eight at each terminal, while for an initial installation of a single circuit only three racks per terminal are needed.

In fig. 8 the four racks indicated provide two complete circuits, although the blank panels on the second and third rack from the left may be equipped for additional circuits.

The type P.A. system, already referred to, provides the same services over its one duplex circuit as the type N system provides over each of its eight circuits. The system is of the single sideband suppressed carrier type and the translation of the audio frequency signals to the high-frequency range is performed in one stage of modulation. Crystal filters are used to separate the lower and upper sidebands (of the single carrier frequency) which are used for the two directions of transmission. The system is described in detail in the article by Goodman.[1]

A typical installation is illustrated in fig. 9 which shows the type P.A. equipment in the E. V. Buchanan Transformer Station at London, Ontario, of the Hydro Electric Power Commission of Ontario. The left-hand rack contains carrier equipment speech and telephone signalling apparatus, and the right-hand rack contains the super-audio transmitting and receiving equipment.

Both type N and type P.A. are normally supplied as A.C.-operated equipments with individual rectifier power packs on each rack; if required, they may both be supplied to operate from station batteries. The type P.A. and type N. systems are finding increasing application in Britain and overseas.

Carrier current methods are also employed for feeder protection and for intertripping and these are described in Sections 6 and 7 of this article.

4. TELEPHONY.

The points at which telephone service will generally be required are as follows:

The central and sub administration offices.
The central control room.
Generating stations and major substations.
Primary and secondary substations on the urban and rural network.

The great variety of requirements for these various purposes renders any attempt at description out of place in the present article.

It is unfortunate that the standard of telephone service which power engineers have come to accept as normal is considerably below that commonly recognised as adequate by the telephone engineer. However, improvements in recent years in carrier frequency systems over long-distance cable circuits have also been incorporated in power-line carrier equipment so that power-line carrier circuits now compare

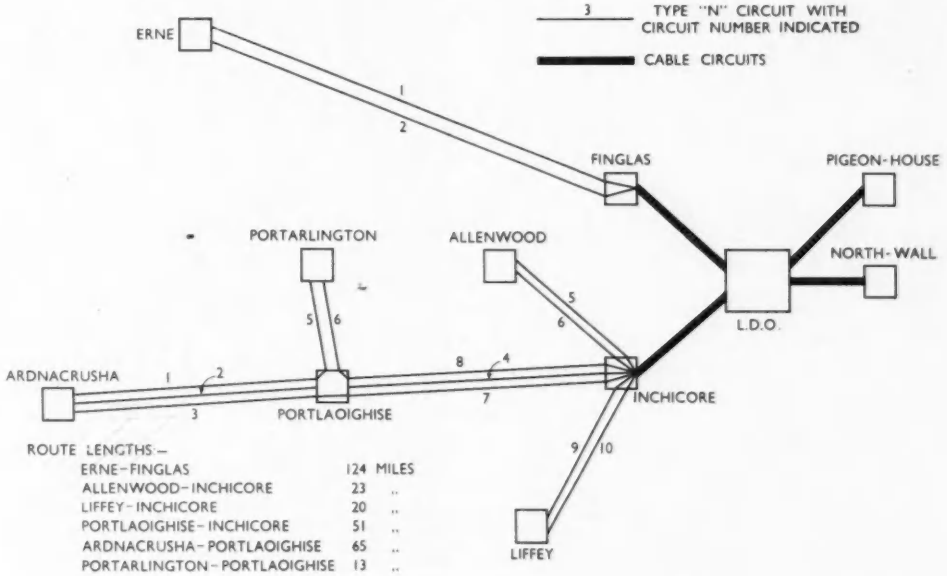

Fig. 7.—Electricity Supply Board of Ireland communications network.

favourably with those provided by alternative means.

Over short distances, say, up to 20 miles, the telephone earth conductor will provide good telephone circuits, and for distances up to 80 miles the use of loading coils enables good quality service still to be obtained over this type of aerial cable.

5. SUPERVISORY CONTROL, INDICATION AND TELEMETERING.

In Sections 2(*b*) and 2(*c*) the broad functions of supervisory control, indication and telemetering were mentioned. A description of the facilities available for these purposes is given in the article by R. W. Field[3] which appeared in this Journal.

In the present article it will not be possible to do more than mention a few of the essential points contained in Field's article and to add a few remarks concerning new techniques which have appeared in recent years.

Under the general heading of " Supervisory Control " two types of system must be considered. The first is that in which the primary purpose of the system is to maintain before a central controller a visual record of the state of the network he is controlling. In general, no actual control of switchgear is effected by the equipments, such control operations as may be required being carried out locally on telephoned instructions from the controller. In such instances the title " Supervisory Control " is not strictly appropriate and " Remote Indication System " seems better ; the B.E.A. uses the title " General Indication System ", or G.I., to cover the back indication of circuit breakers and alarms and the remote metering of loads on feeders and generators.

The second type is the true supervisory control system which, for example, enables switchgear and other plant at an unattended station to be remotely controlled and at the same time maintains before the controller a visual record of the condition of the plant.

Thus systems of the first type might be

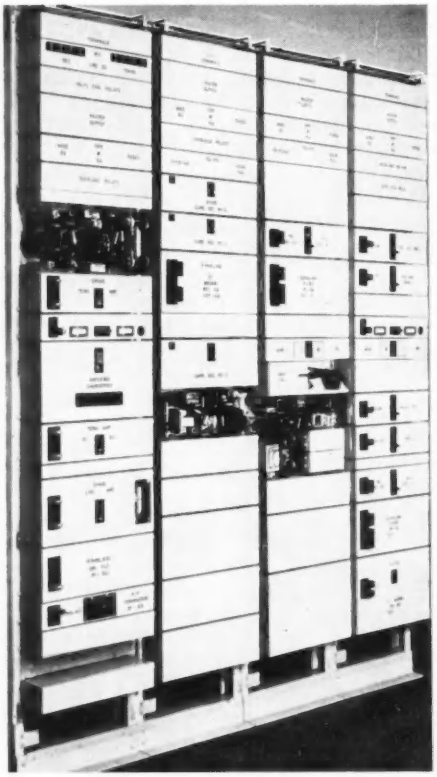

Fig. 8.—Type N power line carrier equipment at Erne, Ireland.

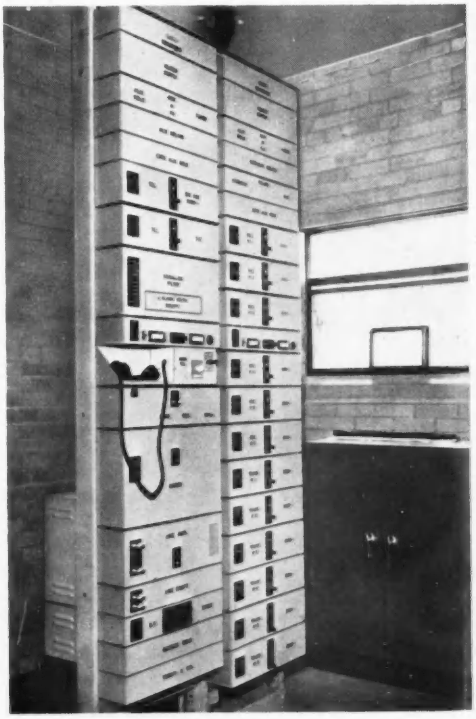

Fig. 9.—Type P.A. power line carrier equipment at London, Ontario.

applied between the central control room and each of the generating stations and major E.H.T. substations, while systems of the second type might be applied between the control rooms in or associated with local generating stations and unattended lower tension transformer stations.

Typical facilities provided on a power network by a supervisory control and back indication system are as follows :

(*a*) Open and close circuit breakers.
(*b*) Change tappings of transformer and boosters.
(*c*) Synchronise supplies.
(*d*) Indicate the position of any of the items listed above.
(*e*) Read amps., volts, kW, kVA, power factor, water pressure and flow, gas pressure and flow and other variable quantities.

Principle of Operation.

The control and indication at a remote point of a number of items of equipment may be effected by the use of selective supervisory control apparatus ; this enables, for example, any item of substation switchgear to be associated, by way of the common signalling channel, with the appropriate control keys and position indicator at the control station.

Fig. 10 shows, in simple form, the principles involved in applying remote supervisory control between a control station and a small substation.

At the control station is a control panel on which appears a mimic diagram representing the whole system. Circuit breakers are represented by discrepancy keys, and transformer tap changing gear by a lever key and indicator. These are so positioned in the diagram as to be associated at a glance with their corresponding plant at the substation. In the example shown it is possible : (1) to open, close and indicate the position of the H.T. circuit breaker ; (2) to open, close and indicate the position of the L.T. circuit breaker ; (3) to change and indicate the transformer tapping ; and (4) to read current and voltage.

Supervisory control equipment can be designed so that these facilities may be provided over a single channel ; if pilot wires are used instead then the number of wires needed is given by the number of connections converging on the selective apparatus shown in fig. 10.

Mode of Operation.

The process of connecting together, over the signalling channel, a particular item of apparatus at the substation and its associated control key and position indicator is termed *selection.*

One particular operation will be considered by way of example, referring to fig. 10 in which discrepancy keys are used. Suppose that the H.T. circuit breaker is open (as shown) ; the handle of the corresponding discrepancy key will lie at right angles to the line representing the H.T. feeder, it will point to the position OI, *open indicate*, and the lamp within the handle will not be lit.

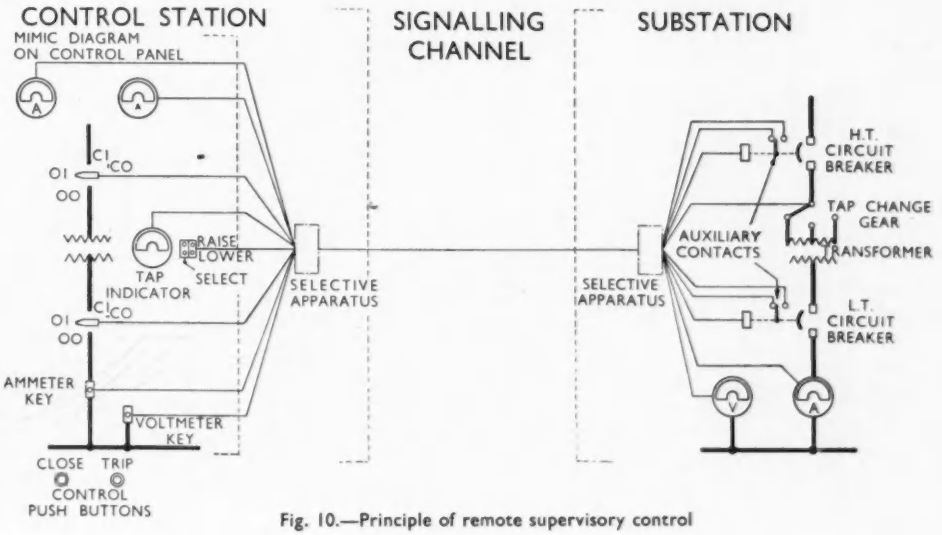

Fig. 10.—Principle of remote supervisory control

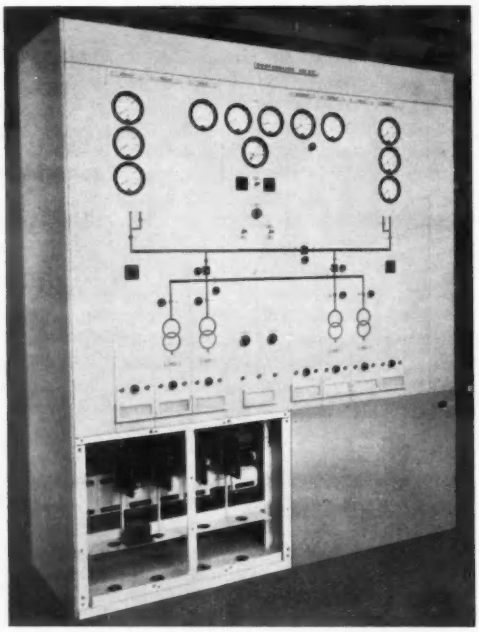

Fig. 11.—Dunfermline control panel.

If it is now required to close the H.T. circuit breaker, the sequence of operation is as follows :

(1) The H.T. circuit breaker key is turned in a clockwise direction to the *close operate* (CO) position.

(2) The lamp in the handle flashes to indicate that the position of the handle does not agree with the actual position of the breaker, while the supervisory apparatus carries out the selection operation necessary to cause the operated control key to be connected via the switching apparatus and the signalling channel to the associated breaker at the substation.

(3) The cycle of operations involved in selection is automatically checked stage by stage and indication of its successful completion is given by a change in the nature of the flashing of the lamp in the handle.

(4) On receipt of the *selection complete* signal the common *close* control push button is operated. This causes signals to be transmitted from the control station to the substation to operate the *close* contactor.

(5) When the H.T. circuit breaker closes, its auxiliary contacts cause signals to be transmitted back to the control station which make the lamp in the discrepancy key handle light continuously.

(6) The handle is now rotated to the vertical *close indicate* (CI) position and, provided that the breaker remains in the operated position, the lamp in the handle goes out and the selective equipment is restored to normal.

In the event of a circuit breaker's being manually operated by the substation attendant or automatically tripped as a result of a fault condition, the supervisory control apparatus selects the affected plant and causes it to be connected via the switching apparatus and signalling channel to the associated control panel indicator, which flashes to indicate that its position is not in agreement with that of the actual breaker. An audible alarm is also given. When the control key is turned to correspond with the new position of the circuit breaker, flashing ceases and the audible alarm is switched off.

All the systems have been designed to ensure that maloperation is nearly impossible, special arrangements being provided to check

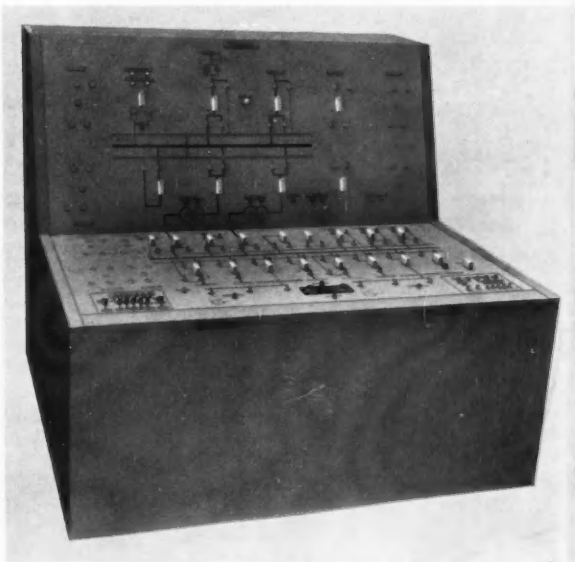

Fig. 12.—Control desk at Salt River, South Africa.

the correct functioning of the control station and substation selection equipment at each stage of the cycle of operations. Any failure results in the selection equipment being released and the lighting of a *fault* lamp on the control panel.

Equipment Features.

The apparatus employed falls under two main headings :

(*a*) Control panel and control-room equipment, and
(*b*) Selective apparatus.

All components used are reasonably small, are readily accessible and are compactly mounted in cabinets or cubicles.

Control Panel.

The control panel is always constructed to meet the specific requirements of the customer and it may form the face of one or more vertical cubicles or it may form the top of a sloping desk.

Fig. 11 which shows the Dunfermline control panel is an example of the former and fig. 12, showing the control desk at Salt River in the Electricity Supply Commission, Cape Western Undertaking, South Africa, illustrates the latter form of construction.

Where many substations are controlled from one control room the control panels can be mounted side by side to form a continuous suite which may be arranged in an arc as illustrated in fig. 13, which shows the Melbourne control office of the Victorian Government Railways.

As already mentioned, switchgear may be controlled and indicated by what is called a discrepancy key ; the use of this key is described in detail in Field's article which also describes an alternative arrangement using a lever-type key.

Where switchgear position has to be indicated but not controlled alternative forms of display are available.

Two alternative methods are available for transformer tap indication. One consists of an indicating meter with a scale divided into the same number of segments as there are tap positions on the transformer it is indicating. The other type of tap indicator comprises a group of telephone switchboard-type lamps, one for each tap position, mounted behind a translucent faceplate on which are engraved the tap position numbers. The associated circuit is arranged to light the lamp behind the number corresponding to the tap on which the transformer tap arm is resting.

Telemetering.

The simplest form of remote metering is the direct system in which the metering current is passed directly over pilot wires to the indicating

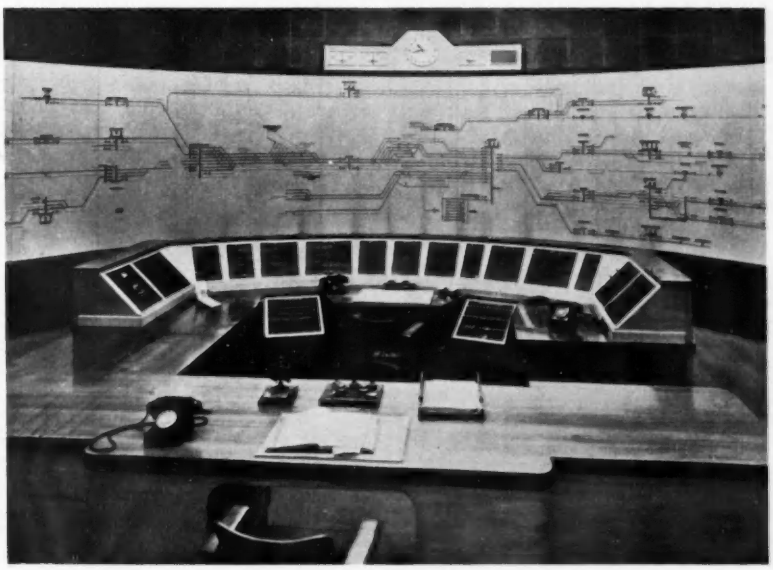

Fig. 13.—Melbourne Control Office of the Victorian Government Railways.

meter. If continuous meter indications are required then a separate pilot-wire circuit must be provided for each meter indication.

If, however, observation of only one meter reading at a time is required, the metering pilots can be switched, via the supervisory equipment, to any of the sources of metering supply and to the associated indicating meter; this is called " on demand " metering.

When the pilot wires are not available for direct metering the measured quantity is translated into a code, of a form suitable for transmission over any type of signalling channel. There are many different forms of coded metering system, a number of which are described in Field's article. For example, if the quantity to be measured is watts or amperes, it may readily be translated into the rotation of a shaft, the speed of rotation being proportional to the quantity to be measured.

The speed of rotation of the shaft may be converted into a frequency by various means, for example by using a slotted disc on the shaft in conjunction with a light source and a photocell. The output of the photocell will be a series of current pulses, the repetition frequency of which is proportional to the original quantity being measured. These pulses may be transmitted either directly or as the modulation of an audio-frequency carrier over the communication channel.

At the receiving station the frequency of the modulation signal may be measured and made to operate a meter, which thus provides an indication proportional to the quantity to be measured at the remote point. A number of different arrangements exist using the variable frequency system.

Another system is the " torque balance " system which can be used for almost any kind of measurement. The principle of operation is illustrated in fig. 14 which shows a wattmeter transmitter.

It will be seen that by means of contacts fitted to the pointer of the wattmeter the follow-up motor may be energised to wind or unwind the balance spring on the meter spindle until equilibrium is established between the opposing torques, and the pointer contact rests between the side contacts. The shaft that winds the balance spring also carries a contact arm which moves over an arc of studs; these are connected to the supervisory apparatus.

The position of the contact arm on the arc of studs is transmitted in the form of a binary code, so that by using a code of 6 or 7 elements any one of 64 or 128 (i.e. 2^6 or 2^7) positions may be indicated.

Selective and Control Apparatus.

This apparatus varies in size and complexity depending on the size of the remote-control installation and upon the operating requirements of the system.

In the larger installations the selective and control apparatus is almost invariably mounted in cabinets normally housed in an apparatus room adjacent to the control room. The apparatus at the substation is housed in similar cabinets to those used at the control station; a typical installation is shown in fig. 15.

The extreme reliability of this equipment is largely due to the use of telephone-type components, such as the relay and uniselector, which have been standardised by the British Post Office and which, for many years, have been used for automatic telephony.

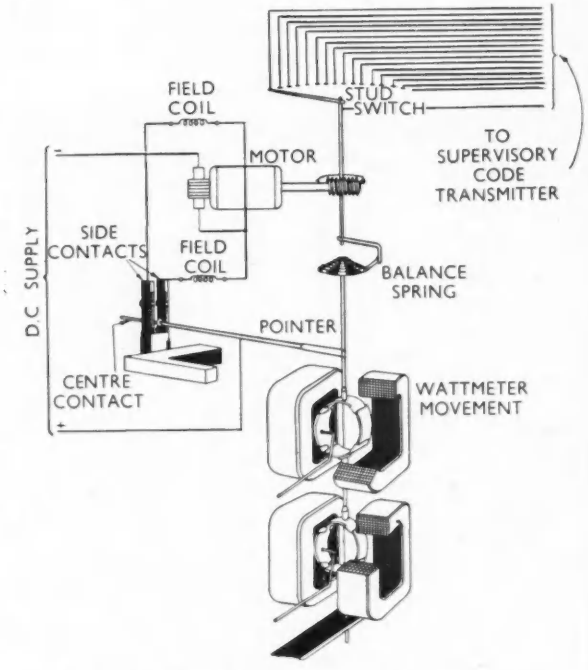

Fig. 14.—Torque balance telemetering transmitter.

6. CARRIER CURRENT PROTECTION.

In protective systems working on the Merz-Price principle it is well known that a comparison of the magnitudes and phase angles of the currents at the two ends of the protected circuit determines whether the protection shall operate or shall remain stable. Telephase protection depends on the same general basic principle for operation, except that when the fault setting current is reached or exceeded a comparison is made only between the phase angles of the currents at the two ends of the protected circuit.

The Reyrolle/G.E.C. Telephase carrier current protection system operates by transmission of carrier currents over the high-voltage lines themselves.

The system comes within the class known as "discriminative" because it initiates rapid tripping of the breakers at both ends of the feeder when the fault is internal, but does not initiate tripping when the fault is external to the feeder.

The features of this system are :

1. Telephase protection gives rapid operation for faults anywhere in the protected zone.
2. Phase-to-phase transmission is used for the high-frequency signals.
3. Voltage transformers are not required.
4. The current transformers employed are standard 15 VA of class C accuracy.

The time which elapses between the incidence of the fault and the energisation of the trip coil depends on the amount by which the fault current exceeds the fault setting current. If the fault current is twice the fault setting value, the operating time is 60 milliseconds.

The maximum length of line to which telephase protection is normally applicable is about 100 miles although sometimes greater lengths of line can be protected.

The complete telephase equipment at each end of the line comprises three main parts, these being the carrier current set, the relay equipment and the line-coupling equipment. The last of these has been described already in the section dealing with carrier frequency transmission over power lines (Section 3(*c*)).

The carrier-current equipment is mounted on one standard 19 in. rack, as shown in fig. 16. The complete telephase equipment is mounted in two cubicles.

Telephase equipment has been provided to the B.E.A., the North of Scotland Hydro Electric Board and to the Electricity Supply Commission of South Africa.

7. INTERTRIPPING.

The essential principles of an intertripping system have been described already in Section 2(*e*). To be really satisfactory the system must fulfil the following requirements :

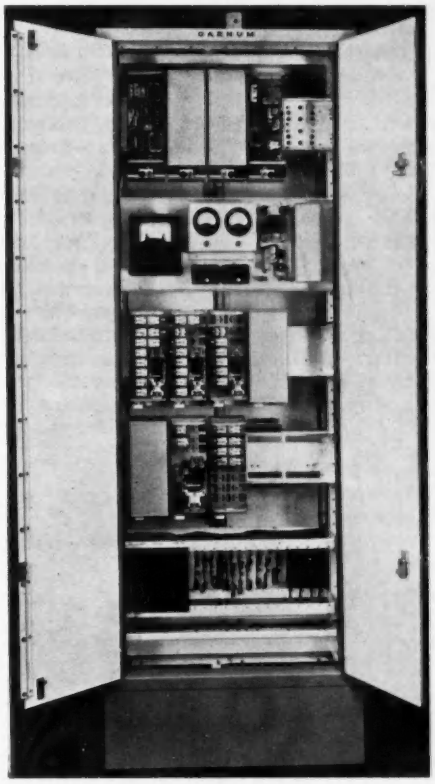

Fig. 15—Substation apparatus cabinet. (Selective and control apparatus.)

1. It must be sufficiently rapid in operation to prevent damage to the transformer.
2. It must be selective to ensure that only the breaker feeding the fault is tripped.
3. It must not be possible to cause tripping by any spurious signals on the communication circuit.
4. It must be completely reliable.

Intertripping equipment has been developed to satisfy these requirements. It provides an interlock between the breaker on the busbar side of the transformer and the breaker at the distant end of the feeder so that when the breaker at one end is tripped a signal is sent over the communication channel, which can take the form of a physical circuit or a power-line carrier channel, to initiate the tripping of the breaker at the other end.

This signal cannot be a simple one as this

would be very liable to the danger of signal simulation by noise, by power surges or by lightning strokes.

By way of example the signal employed in the high-speed carrier intertripping equipment is derived from two carrier frequency currents of frequencies f_1 and f_2, and a low-frequency signal f_0.

Both f_1 and f_2 are modulated by f_0, and in the modulation process f_1 and f_2 are suppressed.

The products of modulation are frequencies $f_1 \pm f_0$ and $f_2 \pm f_0$. These signals are combined and transmitted to line. At the receiving end $f_1 \pm f_0$ is separated from $f_2 \pm f_0$ and the two signals are applied to separate demodulators. The output of each demodulator contains a signal of frequency $2f_0$. These two signals, each of frequency $2f_0$, are then applied to a phase comparison network, which under normal circumstances gives zero output. In order to signal, the phase of one of the supplies of frequency f_0 at the sending end is advanced by 45° relative to the other; at the receiving end the output of $2f_0$, of the channel subject to the 45° phase change, then shifts in phase by 90°. The phase comparison circuit then gives a direct current output to operate a relay and initiate the tripping.

The frequencies f_1 and f_2 differ by 4 kc/s and lie somewhere in the range 100 kc/s to 500 kc/s; f_0 is 40 c/s. The equipment is designed so that one set is capable of providing intertripping for two parallel feeders; in the case of the second feeder the first frequency f_0 is retarded by 45°.

It is not possible in this article to discuss the detailed design of the equipment, which is shown in fig. 17; each rack represents one complete terminal.

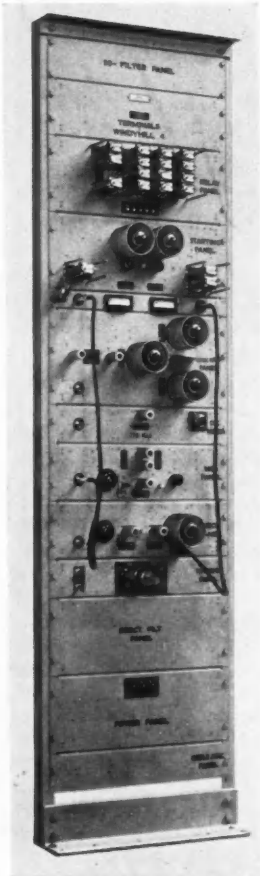

Fig. 16—Carrier terminal equipment for Reyrolle/G.E.C. telephase protection.

8. INDUCTION AND INTERFERENCE UNDER FAULT CONDITIONS.

Wherever power and communication lines come into close proximity there is always the risk of dangerous voltages being set up in the latter mainly by magnetic induction from earth currents under fault conditions.

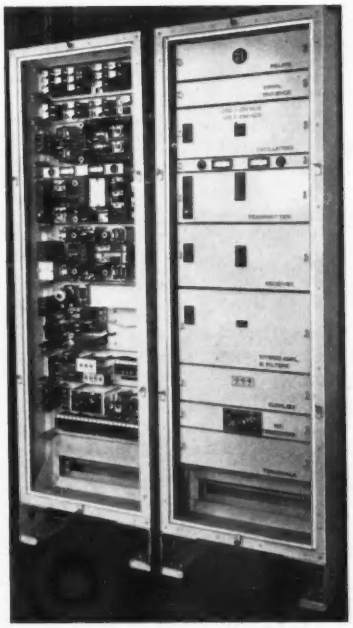

Fig. 17.—High-speed carrier intertripping equipment.

Induction in the telephone circuit takes the form of a longitudinal voltage between the two ends of the circuit and this may set up a dangerous potential between the apparatus connected to the circuit and earth.

Apart from possible damage to apparatus, the danger of electric shock is present as well as acoustic shock to telephone operators and the public.

Various devices are employed to protect personnel and equipment on telephone lines subject to exposure, including fuses, gas discharge devices, drainage coils and isolating transformers.

When a cable such as the telephone earth conductor, described in section 3(*b*), is suspended parallel to a power line, currents will flow in the sheath proportional to the unbalanced (zero phase sequence) power current of the system. These sheath currents are caused by magnetic coupling between the power circuit (with earth return) and the circuit formed by the cable sheath and earth.

These currents are not usually significant under normal load conditions but can assume large values under earth fault conditions, as for example when a flashover occurs between the phase and earth conductors. There is then, in addition to the magnetically induced current, a component of the fault current which returns to earth through the earth conductor sheath.

Thus the current in the sheath may vary from point to point along the line and may attain values of many hundreds of amperes. The magnitude of the sheath current at each point along the line depends on a number of variable factors such as the characteristics of the power network, the position of the fault, the earth resistivity, the values of individual tower earthing resistances and, to a lesser extent, on the spacing between the telephone earth conductor and the phase wires.

Due to the sheath impedance, the current flowing in the sheath gives rise to a voltage difference between the telephone core and the sheath. This voltage is very small under normal conditions but, corresponding to the large currents under fault conditions, it can assume large values. It is necessary, therefore, to ensure that this voltage cannot exceed the breakdown strength of the insulation of the cable or of the terminal isolating transformers, namely 15 kV.

If calculation shows that this breakdown strength might possibly be exceeded then the telephone earth conductor has to be sectionalised by isolating transformers.

The effect of external interference on the communication circuit is kept to a minimum due to the accurate balancing of the conductors of the telephone circuit.

ACKNOWLEDGMENT.

The author would like to express his thanks to the Chief Engineer of the Electricity Board of Ireland for permission to use the information shown in figs. 5 and 7.

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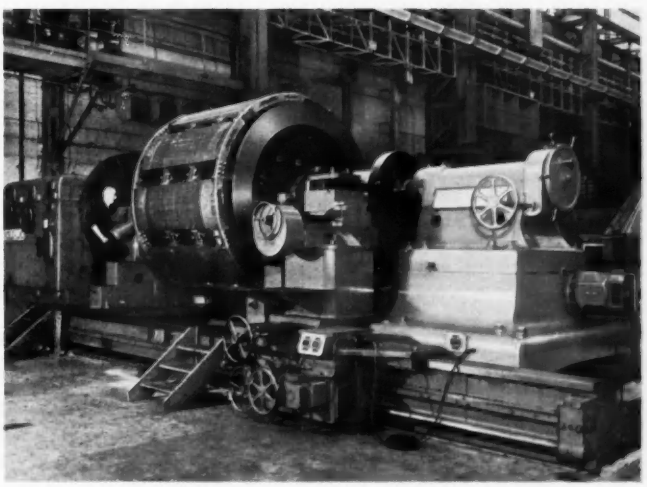
Hydro-electric Plant in Tasmania

Two of the five 25 MW, 600 r.p.m. vertical shaft alternators for the Tungatinah Power Station of the Tasmania Hydro-electric Commission are in service. The illustration shows the magnet wheel of one of these alternators being machined in the Witton Engineering Works.



A Modern Thermal Pattern Relay for Motor Protection

(Part 1)

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Chamberlain & Hookham, Ltd.

The most recent addition to the range of protective relays developed by Chamberlain & Hookham, Ltd. is the thermal pattern motor protection relay. In this article the author indicates the technical problems presented to the designer by the intricacies of a device of this type, and the care required in manufacture to produce an instrument which will function accurately under all conditions of service.

INTRODUCTION.

FOR many years thermal pattern relays have been available for the protection of induction motors against overloading, but only in the last decade or so have satisfactory relays been available for phase-unbalance protection. The earlier overcurrent relays were not compensated for ambient temperature changes, on the assumption that such a change would affect motor windings and relay characteristics alike, the speeding up of relay operation by increased ambient temperature corresponding approximately to the shorter overload time permissible on the motor. However, the modern practice of centralising auxiliary plant control panels in large installations such as power stations, etc., renders such an assumption void, as the relay is often a great distance from its associated motor, and wide temperature differences between the motor and relay environs may occur. The present practice, therefore, is to use a thermal relay giving both overcurrent and phase-unbalance protection, the operation of which is independent of changes in ambient temperature.

Before describing the new relay* it is as well to consider the construction and performance of conventional pattern thermal relays previously obtainable. The overcurrent relay consists essentially of two bimetal spirals, one of which is fixed at its inner end and is heated by an element carrying line current. The second bimetal spiral is shielded from the heater and has its inner end freely pivoted and attached to a contact arm. The outer ends of the two spirals are coupled together so that the contact arm deflection due to ambient temperature change is the difference of the respective deflections of the two spirals. If the two spirals are similar in all respects the resultant contact arm deflection due to ambient temperature change is zero. Thus the deflection of the contact arm depends only on the current flowing through the heater; for overcurrent protection the contact arm may be associated with a cali-

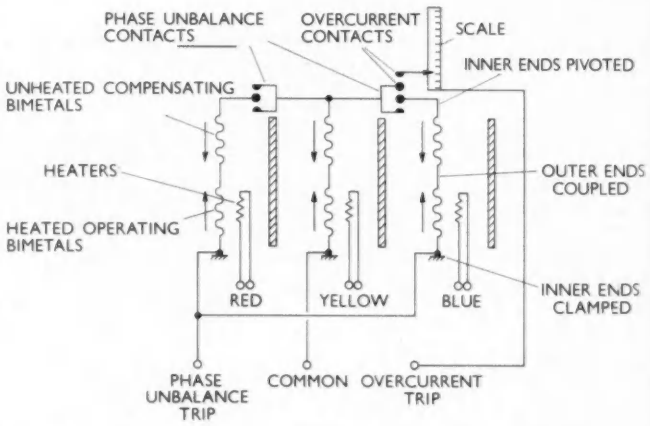

Fig. 1.—Schematic diagram of conventional pattern thermal relay.

* British Patent No. 701,931.

rated scale and adjustable contact. If two such units are now associated, having a common axis, with the contact arm of one in the shape of a wo-pronged fork enclosing the contact arm of he second, so that the two contact arms make onnection with each other if their deflections liffer by more than a predetermined amount, he result is a relay giving phase unbalance rotection for two line currents. The addition of a third similar unit gives protection against phase unbalance for three line currents and, by adding a calibrated scale and adjustable contact to one of the units, overcurrent protection is also obtainable. A diagrammatic representation of such a relay is shown in fig. 1.

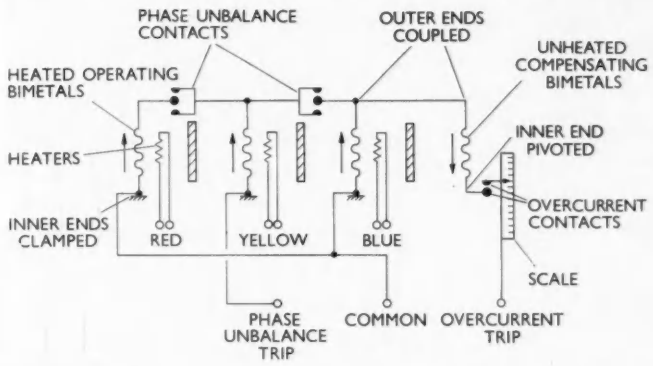

Fig. 2.—Schematic diagram of type H thermal relay.

It will be noted that of the six bimetal spirals used in the above arrangement, three are used for the sole purpose of temperature compensation and that a saving in the number of spirals can be achieved by comparing uncompensated deflections of the operating spirals as shown diagrammatically in fig. 2 and isometrically in fig. 3. The Chamberlain & Hookham type H relay has been designed on this principle, and while retaining the advantages and accuracy of the conventional relay, is of simpler construction and can be accommodated in a smaller case. Consideration of fig. 2 will show that while each heated bimetal is not compensated for ambient temperature change, the relative motion between the phase unbalance contacts is in fact independent of ambient temperature. Thus the removal of the two spirals has in no way been detrimental to the temperature compensation of the relay.

In the discussion above no reference has been made to another method of temperature compensation, namely torque balance, in which both operating and compensating bimetals are fixed at one end and exert opposing torques on the contact arm. This means that the compensating spiral torque must be overcome by that of the operating spiral before the contacts can close, and both spirals are under stress which may give rise to permanent setting or fatigue. For these reasons, together with the instability which may result, torque balance is a method to be deprecated, and has been avoided deliberately in the design of the type H relay.

THE BIMETAL SPIRALS.

The bimetal spirals are perhaps the most important components of the relay as they directly impart motion (and ultimately pressure) to the contacts. The theory of differential expansion of two dissimilar metals permanently attached to each other at a common interface is already well known, and it will be sufficient to recapitulate the approximate formula for the angular rotation between the ends of a bimetal spiral:

$$\theta = \frac{KTL}{t} \text{ angular degrees} \qquad (1)$$

Where K = a " constant "
L = free length of bimetal
T = temperature rise °C.
t = thickness of bimetal.

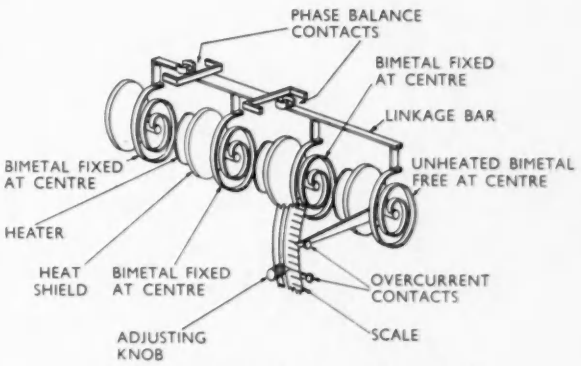

Fig. 3.—Isometric sketch of type H thermal relay.

This formula, giving a linear relationship between θ and T is true only over a limited temperature range beyond which K is no longer a constant, but decreases with increasing temperature. This fact seems at first to be a disadvantage, but further consideration shows that when the relay has closed its contacts and the heater current has ceased, stored heat will continue to flow from the heater to the bimetal, and the contact pressure will continue to build up. If K decreases with increasing temperature the stress in the bimetal due to the mechanical restraint will be correspondingly less, and by the correct choice of material, the decrease in K will be such as to limit the self-disrupting forces at the interface to a safe value. The material used in the type H relay is a nickel/nickel-alloy bimetal and has this desirable feature without loss of linearity over the normal working range of bimetal temperatures. Fig. 4 shows a typical deflection/temperature characteristic for this material.

The initial slope of the curve shown in fig. 4 was chosen as a compromise between two conflicting requirements. In order to restrict the motion of the contacts, and thus avoid undue weakening of structural members of the relay, a small slope is desirable, but, on the other hand, too small a slope compresses the overcurrent scale and renders accurate setting more difficult. For any specific material there is a constant ratio L/t which will give the desired slope, and if the outside diameter of the spiral is fixed the space between adjacent turns will be inversely proportional to the square of the thickness. Alternatively, for a given spacing between turns, the outside diameter will increase in proportion to the square of the thickness. The choice of thickness is therefore a compromise between excessive flexibility on the one hand and interturn friction on the other. In the type H relay the thickness of the bimetal is approximately equal to the spacing between adjacent turns.

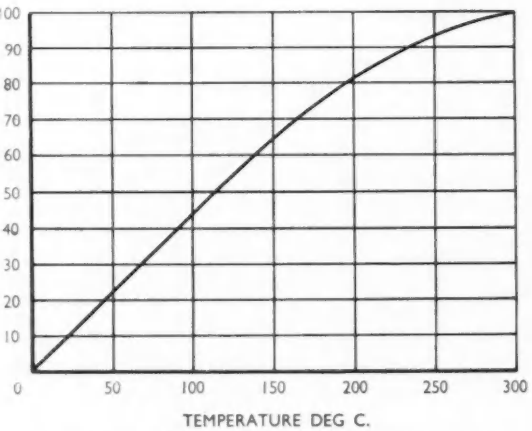

Fig. 4.—Typical deflection/temperature characteristic for bimetal spiral of type H relay.

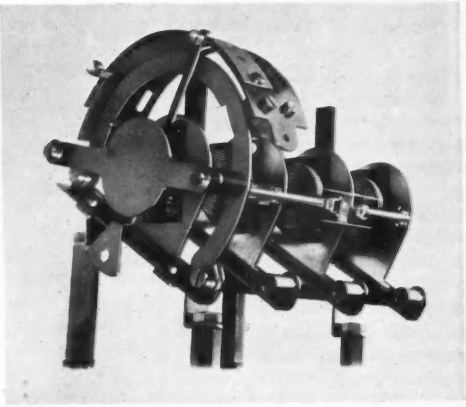

Fig. 5.—Bimetal spirals ready for oven test.

The winding of bimetal strip into a spiral introduces internal stresses which, if allowed to remain, cause dimensional instability and deflectional hysteresis during the useful life of the spiral. In order to remove these stresses, the spirals used on the type H relay are submitted to heat treatment at this and subsequent stages in the manufacturing process. The spiral is then ready for attachment to the central hub by the use of a suitable tin-lead alloy.

The transfer of heat from the heater to the bimetal is partly by convection and partly by radiation, and it is obviously important that the absorption coefficient of the bimetal surface should remain constant if the calibration of the relay is to remain stable throughout its useful life. Most metals develop a surface film when heated and exposed to the atmosphere and the absorption coefficient may vary with the passing of time. A method of reducing such possible changes to a minimum is to electroplate the bimetal spirals with a metal such as platinum, gold,

chromium, or antimony[1] which belong to the small group of tarnish-resisting metals. Of the four metals mentioned, antimony is the most desirable on economic grounds, but electrodeposition of this metal is very difficult, the deposit being in the form of small nodules which are easily detachable. Many attempts have been made to use this material, but so far without success. Of the other metals mentioned chromium has poor " throwing power " for plating between turns of the spiral; platinum, when electroplated, tends to be a dull grey easily stained deposit. Gold, with its attractive clean lustre and superior tarnishing resistance therefore has been chosen as the plating material and is deposited over a thin flash plating of copper to ensure better adhesion to the bimetal.

Each spiral is then fitted to a testing jig in which the free end of the spiral is attached to an indicating pointer by means of an adjustable clamp. The difference in deflection of the pointer for two fixed temperatures is noted and the free length of the bimetal L is adjusted until the required temperature/deflection characteristic is obtained. After such calibration the contact arms and contacts are attached to the spirals, which are then mounted on a relay framework as shown in fig. 5. The position of the phase-unbalance contacts relative to the relay framework is established by means of a simple assembly device calibrated in terms of the ambient temperature prevailing at the time of assembly.

The riveting of a contact arm on to each bimetal spiral is subject to human error, manufacturing tolerances, etc., and it is necessary to check that the effective ratings of the four spirals on each relay assembly are still identical. This is done by mounting a number of the assemblies shown in fig. 5 on a testing panel which is then placed in a specially constructed oven having a large double window for observation. Relays which are not correctly temperature compensated are rejected after observation of their behaviour over a range of temperatures.

The oven briefly described above, and the bimetal rating equipment, were not obtainable commercially but were developed and constructed on the Company's premises. A view of the complete equipment is shown in fig. 6; the oven is on the left-hand side, and the bimetal rating equipment is on the right-hand side.

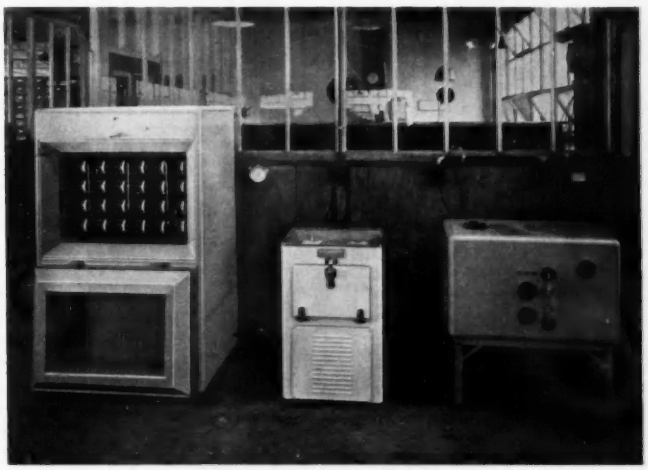

Fig. 6.—Testing equipment for bimetal spirals.

THE HEATERS.

The use of high voltage motors increases the design problems of associated protective gear current transformers because of the low primary ampere turns available, and it has become increasingly important to reduce the secondary burdens wherever possible. This problem is eased a little if the transformers are wound with 1 amp. secondaries instead of 5 amp. secondaries, as the lead burdens are thereby reduced to one-twenty-fifth of their previous value, but it was not possible to take advantage of this with the conventional relay because 1 amp. heaters were not available. By careful design 1 amp. heaters have been produced successfully for the type H relay and the burden of the relay itself has been nearly halved, the burden being approximately 2·25 VA per phase compared with approximately 4·0 VA per phase for the conventional pattern relay. A further advantage of this reduced burden is that the range of fault currents covered by the relay is increased from four times normal current to six times normal current without endangering the heaters.

The usual construction of heater consists of a flat conductor of high resistance clamped between discs of mica for support and insulation, the diameter of the discs being slightly larger than the diameter of the associated bimetal spirals. A 1 amp. heater demands a long

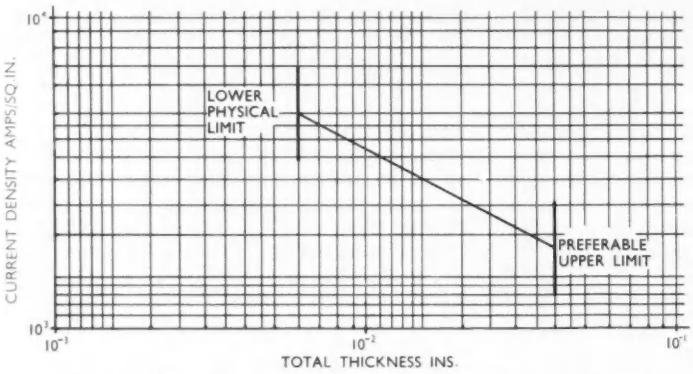

Fig. 7.—Relationship between current density and total heater thickness.

conductor of small cross-section and this represents a difficulty in production where flimsy, easily damaged structures can be a source of annoyance and inconvenience. It was therefore decided to use practically the whole of the area of the mica discs for the heater instead of a smaller area near the centre, and to obtain twice the length of conductor by folding the heater back on itself, with a mica disc in between as insulation. By this means it was possible to produce a relatively robust heater, with the necessary resistance, and yet avoid undue overall thickness. The theoretical considerations of such folding are as follows:

Let the total metal thickness of the heater be d, and let the surface of one side of the heater remaining after cutting, slotting, etc., be A, then if this be considered as cut into strips of breadth b and thickness d/n folded on itself $(n\text{-}1)$ times, the total length of strip will be An/b. The resistance of such a strip of material, having a specific resistance ρ, is given by the equation

$$R = \frac{\rho An}{b}\,\frac{n}{bd} = \frac{An^2\rho}{b^2d} \qquad (2)$$

Hence, assuming that the heat lost from the edges is negligible, the watt loss per unit area W for current I is given by

$$W = \frac{I^2n^2\rho}{2b^2d} \qquad (3)$$

Restating equation (3) in terms of current density D we have

$$W = \frac{D^2d\rho}{2} \qquad (4)$$

For a constant temperature rise for corresponding currents over a range of heaters W must be constant, and assuming ρ is constant we have the relationship

$$D \propto d^{-\frac{1}{2}} \qquad (5)$$

This also means that for a fixed total thickness of metal, heaters of varying current sizes work at the same current density for the same temperature rise irrespective of the number of times the heater has been folded. Thus a folded heater behaves in exactly the same way as a single layer heater, the only criterion being the total metal thickness. A curve showing the relationship between D and d for a watt loss of 1·75 watts per sq. in. is shown in fig. 7. The minimum value of d is determined by the thinnest material commercially available which is in the region of ·006 in. The greatest value of d is approximately ·040 in. and is determined by constructional difficulties and the fact that heat loss from the edges can no longer be ignored.

The heater is produced from a standard blank of nickel-chrome alloy or nickel-chrome-iron

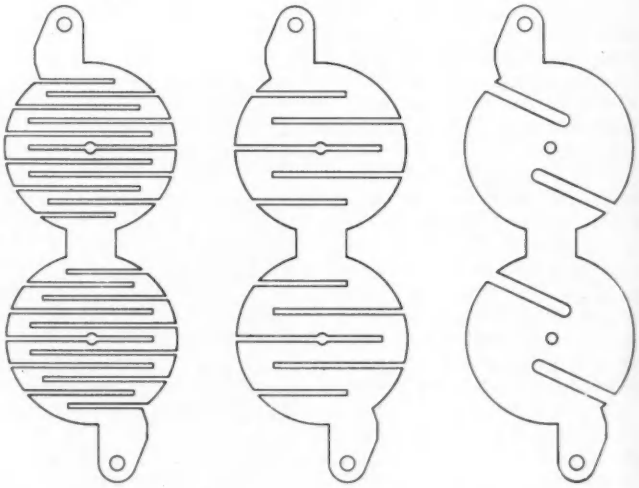

Fig. 8.—Typical heater arrangements from one blank.

alloy by slotting from alternate edges. Fig. 8 illustrates how the same blank is slotted in different manners for three sizes of heater. The result in each case is a conductor of the required length and cross-section spread evenly over the whole available area. Tellurium-copper terminals are then riveted and brazed to the heaters by means of the holes at their extremities, before passing the heaters to an individual resistance test which is carried out on a Kelvin Double

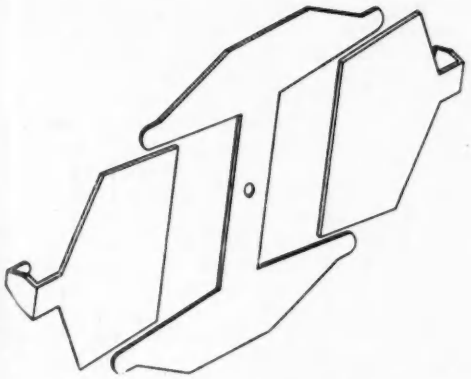

Fig. 9.—Isometric sketch of lag plate.

Bridge to obviate any errors due to contact resistance. By extending individual slots with a small rectangular punch the resistance is brought within acceptable tolerances, there being no difficulty in adjusting heaters within $\pm$ 1 per cent of nominal.

Although the grid-like design discussed above gives a well-distributed heat pattern, a further improvement in heat distribution can be obtained by including a thin plate of metal (insulated by two discs of mica) between the two lobes of the heater. The metal plate reduces the rate of temperature rise of the heater because of two distinct mechanisms, and is therefore termed a lag plate. The obvious first cause of temperature lag is that the metal plate absorbs heat before its own temperature can rise, and the second cause is that the metal plate re-emits some of the heat through the spaces between the heater bars. When time tests are carried out on the completed relay it may be necessary to alter this delay slightly to achieve equal deflection on all three phases, to which end the lag plate is constructed of three separate pieces, two of which are removable, as shown in fig. 9. The material used is the same as that from which the heater is constructed.

Fig. 10 shows the complete heater assembly with one part of the lag plate withdrawn. Four pieces of mica, the heater, and lag plate are clamped together by four claws of a supporting spider which are disposed symmetrically around the periphery of the mica discs. Two further claws of the spider are used as spacers and are riveted to the circular heat shield which is produced from a special resin-bonded asbestos material having good heat resistant properties. These two claws have holes pierced in them through which the tongues of the two removable parts of the lag plate may be inserted and bent over, to form a simple but effective securing device. The heat shield also acts as an insulator, there being no electrical contact between the spider and the main support member which latter is riveted to the centre of the heat shield. The main support member has been designed for maximum rigidity compatible with minimum heat transfer as it is essential that each heater shall influence one bimetal spiral only. The terminals are robustly housed in insulating bushes attached to the main support member which is terminated in calibration screws adapted for the positional adjustment of the heater relative to its associated bimetal spiral. These calibration screws have spring loaded friction devices for ease of adjustment, and are fitted with locking nuts.

When a high voltage is applied between the heater and the main member for the purpose of checking the insulation, the metal spider would normally be at some indefinite potential between the two, and discharge streamers may occur across the faces of the mica discs from the heater

Fig. 10.—Typical heater element with lag plate partially withdrawn.

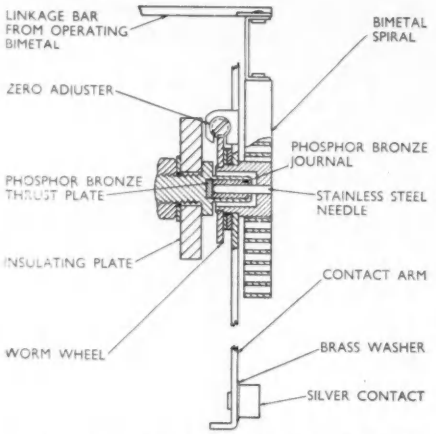

Fig. 11.—Part cross-section of pivoted bimetal spiral.

to the claws of the spider. This harmless but undesirable discharge has been avoided by cutting away a small portion of the mica disc facing the heat shield, at a position immediately under one of the four claws to ensure electrical connection between the heater and spider.

THE BEARINGS.

The design of a bearing for the compensating bimetal spiral must take into account problems relating to friction, protection from the ingress of dust, freedom from rusting, etc. Consequently the bearing used on the type H relay has been constructed from a stainless steel needle running in a phosphor-bronze journal, and having its domed end resting against a phosphor-bronze thrust plate, the whole bearing being enclosed by the hub of the spiral in the form of a dust cap as shown in fig. 11. The journal and thrust plate are mounted in a brass housing which is secured to the centre of a plate of insulating material, there being no metallic connection between the bearing and the main support member. The large bearing surfaces provide controlled friction which damps out any oscillations set up by externally applied vibration while at the same time having no detrimental effect on the operation of the relay.

THE CONTACTS.

The hub shown in fig. 11 has a worm-wheel riveted to its inner end, retaining a spring washer and an aluminium-alloy contact arm against a further shoulder on the hub. Two ears on the shorter end of the counterbalanced contact arm act as bearings for a worm which, in conjunction with the worm-wheel, forms a contact arm zero adjustment. A screwdriver slot in the end of the worm facilitates this adjustment, the friction caused by the tension of the spring washer giving adequate security against rotation by vibration. The end of the contact arm is bent over to form an indicating pointer and is associated with the percentage load scale. The contact is made from a rectangular piece of silver pressed up into the shape of a cup having two breaks in its cylindrical wall as shown in fig. 12. This method of construction gives a large surface area for cooling, and reduces the weight of material, thereby easing counterbalancing problems.

The use of aluminium-alloy contact arms (for lightness) and silver contacts may introduce a corrosion problem unless certain precautions are observed. Two dissimilar metals connected together in the presence of an electrolyte form a short-circuited primary cell and circulating electric currents flow, the electronegative metal suffering electrolytic attack. Condensed moisture at such a joint would not normally be expected to cause electrolytic corrosion as distilled water is such a poor conductor, but in practice such moisture usually contains salts absorbed from dust, etc., which may give rise to electrolytic corrosion if the potential difference between the metals is excessive. It is difficult to generalise in this respect, but an accepted maximum potential difference for interior parts which may be exposed to condensation but not to contamination with salt is 0·5 volt, measured in sea water[2]. An estimate of the likely potential difference which will occur between two metals is obtained by comparing the potentials of each metal with a calomel electrode in sea water. The potentials for aluminium-alloy and silver on this basis are —0·75 volt and +0·01 volt respectively, giving a difference of 0·76 volt which exceeds the suggested limit above. While it was realised that the amount of moisture

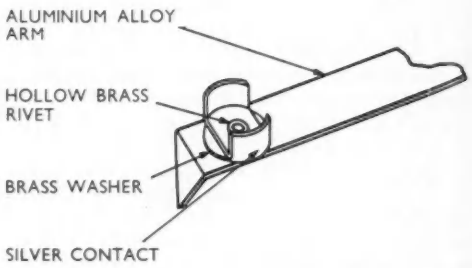

Fig. 12.—Method of attaching contact to contact arm.

likely to be met in this particular application is small, it was nevertheless decided to guard against possible trouble from this source, and an interposing washer and hollow rivet, both of brass, were used to link the two metals. Brass has a potential of —0·3 volt with a calomel electrode in sea water and hence the potential difference at the aluminium-alloy/brass joint is 0·45 volt, and that at the brass/silver joint is 0·31

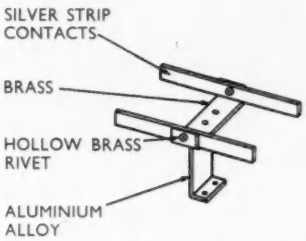

Fig. 13.—Construction of phase-unbalance contacts.

volt, both of which are within the suggested limit above.

Associated with the overcurrent contact is a " fixed " contact adjustable at will by unlocking a knurled insulating knob, setting the contact to the desired position on the scale with the aid of an index, and relocking the insulating knob. The adjustable contact itself is similar to that shown in fig. 12, but as the contact carrier is plated brass there is no necessity for an interposing brass washer. A guide for the adjustable contact is formed by a slot in the scale carrier, through which pass two locating tongues of the index together with the contact carrier locking stud on which the insulated knob is threaded.

The aluminium-alloy link joining the outer end of the compensating spiral to the outer end of the blue phase spiral is extended towards the yellow phase spiral and has a similar contact to that shown in fig. 12 with an interposing washer. A similar construction is used for the red phase contact arm which also points towards the yellow phase spiral. The yellow phase contact is constructed from two strips of silver riveted to a brass carrier which is in turn attached to the aluminium-alloy link as shown in fig. 13. The function of the H-shaped construction is to enclose the contacts on the other two spirals so that only a predetermined relative rotation between two adjacent spirals can occur without the contacts closing, the separation between the two silver strips having been chosen so that a difference of approximately 12 per cent between the currents of adjacent heaters, when one of them is carrying full load current, will just close the contacts. The electrical circuit of the contacts for phase-unbalance protection is through the two bimetal spirals which are associated with the unbalance ; and for overcurrent protection is through the scale carrier, adjustable contact, contact arm, compensating bimetal, linkage bar, and heated bimetal, as shown diagrammatically in fig. 2. It will be seen that an electrical connection to the centre of each heated bimetal spiral is necessary, and this is achieved by locking the central hub of the spiral to a metal strip supported on an insulating panel and brought out to a suitable position for a connecting terminal as shown in fig. 14.

THE BALANCE WEIGHTS.

Each bimetal spiral will assume varying positions during the operation of the relay as a result of changes in ambient temperature and heater current, and in order that no inaccuracy of tripping values shall occur it is necessary to correct any static unbalance of the bimetal spiral assembly caused by inherent asymmetry of the spiral itself and the presence of contact arms, etc. A thin spiral having equally spaced turns may be represented graphically by a polar equation of the form:

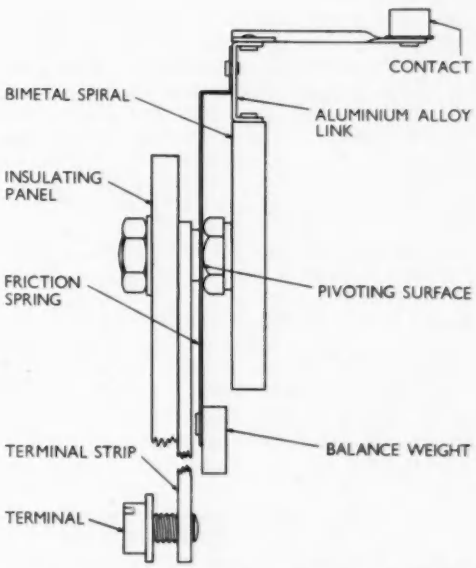

Fig. 14.—Typical balance-weight assembly for heated bimetal spiral.

$$r = k\alpha \qquad (6)$$

Where r = radius vector from origin to point on spiral.
α = angular rotation of radius vector in radians from a fixed line passing through the origin.
k = constant.

The distance between adjacent turns of such a spiral is given by $2\pi k$ and it can be shown that the displacement of the centre of gravity from the origin is approximately equal to $2k$ if terms including $1/\alpha$ can be neglected, which is the case for the type H relay spiral. For this spiral the constant k is approximately 0·01, but the central hub is symmetrical and approximately one-third of the weight of the spiral so that the anticipated displacement of the centre of gravity is rather less than 0·015 in. It will be seen therefore that although k may change slightly due to expansion or contraction of the spiral under working conditions, the inherent asymmetry of the spiral is negligible.

The presence of the contact arms, etc., cannot, however, be ignored and counter weights are necessary to restore the static balance of each spiral assembly. It might be thought that this could be accomplished by attaching a similar weight to the spiral diametrically opposite to the contact arm, but further consideration will show that the spiral is not capable of transmitting opposing moments, and this method results in the addition of the two translatory forces due to the contact arm and balance weight which in combination offset the spiral downwards, irrespective of its rotational position. In order to obtain effective balance it is therefore necessary to arrange the contact arm and balance weights on opposite ends of a rigid lever having a controlling pivot between them. This is accomplished without difficulty in the case of the compensating bimetal which already has a pivot and may be counterbalanced by an extension beyond the pivot. The balance weight in this case consists of the zero adjustment worm already described above together with a sector shaped " tail " in which a hole is pierced. The size of this hole is adjusted for each assembly to obtain accurate static balance.

In the discussion on bearings for the compensating bimetal spiral the desirability of controlled friction was mentioned ; the same principle has been applied to each of the heated spirals as shown in fig. 14. A light spring is loosely riveted to the aluminium-alloy link so that it is self-aligning and is lightly sprung against an annular face on the central hub, applying controlled friction to the spiral assembly. The spring has a slotted aperture to accommodate the hub spigot and is continued beyond the radius of the spiral, terminating in a balance weight the size of which is dependent upon the associated contact arm assembly.

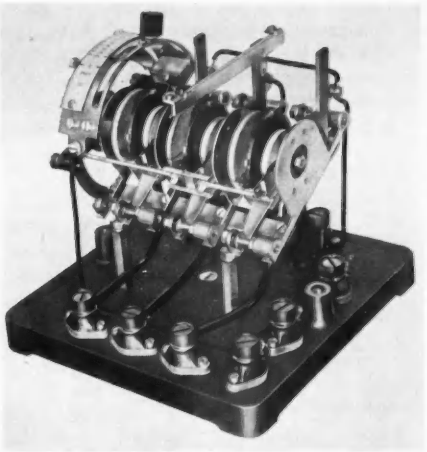

Fig. 15.—Type H relay, with cover removed.

With the above provisions for static balancing of the moving parts and the inclusion of controlled friction it was anticipated that the relay would be rendered less liable to operation on marginal settings by external vibrations. It has been found that the relay is not subject to resonance when vibrations of magnitude 0·1 in. are applied at any frequency up to and including 500 cycles per minute, the latter figure being arbitrarily chosen as the maximum to be expected in practice. In addition to giving this excellent performance the relay suffered no detrimental effects when subjected to the higher frequency vibrations for long periods.

GENERAL ASSEMBLY.

The separate bimetal sub-assemblies are mounted on two main members which are attached to four supporting pillars. Bosses riveted to these sub-assemblies are drilled and tapped to receive the adjusting screws of the heater sub-assemblies, and the completed assembly, minus the main label is as shown in fig. 15. The method used for the assembly ensures adequate strength, while at the same time presenting long heat-conduction paths of small cross-section between each heater and any other sub-assembly. The main label is normally attached to the metal strip on the bimetal spiral insulating plate near the centre of the relay and is insulated from all live parts.

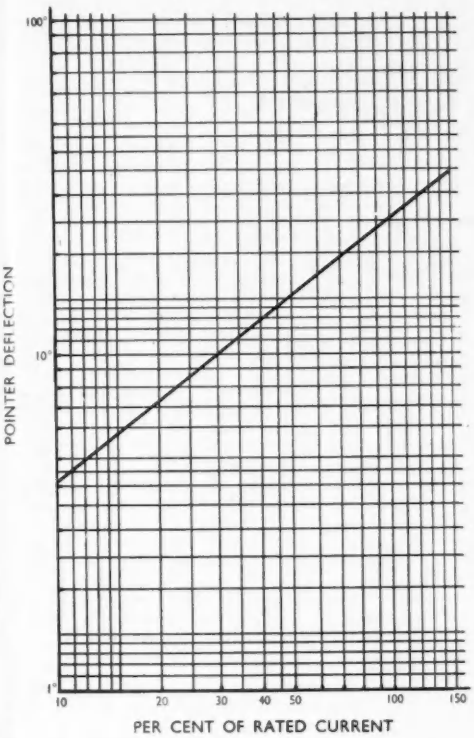

Fig. 16.—Relationship between current and pointer deflection.

With the cover removed for testing purposes the compensating spiral may be exposed to draughts or sunlight, from which the other spirals are shielded by the relay structure, and in normal operation this spiral would have the fastest response to ambient temperature changes. In order to avoid these shortcomings a metal plate, slightly larger than the spiral, is attached to the adjustable contact carrier to form a shield as clearly shown in fig. 5. The inclusion of a small domed rivet in the centre of this shield prevents excessive end play of the spiral on its bearing during transport.

THE OVERCURRENT SCALE.

The overcurrent scale has already been mentioned in the description of the adjustable contact, and forms a ready means of determining the running load of the motor as well as providing a guide for setting the adjustable contact. The deflection of the associated contact-arm/pointer is affected by the current flowing through the heaters and the scale could be calibrated in amperes. This method would, however, be rather inflexible, requiring many scales with different current calibrations, and the simple expedient which has been adopted is to mark the scale in percentages from 50 per cent to 150 per cent where the rated current of the relay is regarded as 100 per cent. There is also a zero mark for calibration purposes. In practice it has been found that the disposition of the calibration marks is so consistent between relays that it is possible to use a printed scale without incurring any appreciable error, provided the relay is accurately adjusted at 125 per cent.

Fig. 16 shows the relationship between the pointer deflection and heater current, plotted on logarithmic scales. An interesting feature of this curve is that it has a slope of approximately 1·719 whereas the expected figure would be 2·0 since the energy dissipated by the heater is proportional to the square of the current. Assuming that a constant proportion of the heater energy is received by the bimetal at all currents when heat transfer is in equilibrium, it is possible to calculate the cooling law of the spiral, as follows. The rate of heat loss from the spiral may be expressed in the form pT^q where p and q are constants and T is its excess temperature over the surroundings. Thus for any current I the heat flow equation of the spiral is

$$mI^2 = pT^q \qquad (7)$$

Where m = constant.

Over the limited range of temperatures involved, the excess temperature of the spiral is proportional to its deflection as shown in fig. 4, and hence is proportional to $I^{1·719}$. Substituting this value in equation (7) we have

$$mI^2 = sI^{1·719q} \qquad (8)$$

whence the constants m and s are equal, and $q = 1·163$. From Stefan's Fourth Power Law, applied to small values of excess temperature T, the rate of heat loss due to radiation is proportional to T, and from Langmuir's work[3] the rate of heat loss due to natural convection for a vertical disc is proportional to $T^{5/4}$ whence it would appear that the mechanism of heat flow from the spiral is part radiation and part convection, the value 1·163 lying, as it does, between 1 and 1·25.

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3. LANGMUIR, *Trans. Amer. Electrochem. Soc.*, Vol. 23, p. 299 (1913).

TECHNICAL LITERATURE

A DIGEST OF RECENT BOOKS, ARTICLES AND PAPERS, BY MEMBERS OF THE G.E.C. AND ITS ASSOCIATED COMPANIES

RELAYS FOR ELECTRONIC AND INDUSTRIAL USE

By the late R. C. Walker (Valve and Electronics Department).

Chapman & Hall, 303 pp. Price 42/-.

This book brings together in collected form for handy reference, the principal features and potentialities of relays as switching devices. Although in extensive use for many years, relays have received relatively little attention in technical literature.

The simplest forms of relay are common knowledge, but the extent to which they can be incorporated in elaborate circuitry to secure discriminating, summating, mastering and many other types of control are insufficiently appreciated.

Particular attention is given to the vast quantity and variety of light mechanisms and switching devices brought into existence by the rapid expansion of electronic devices in recent years. The text is fully descriptive and generously illustrated.

ELECTRIC TRAINS AND LOCOMOTIVES

By B. K. Cooper (Publicity Dept., Head Office).

Leonard Hill Ltd., 128 pages. Price 15s.

The principles of electric traction are described with special reference to their application in recent designs of locomotives and motor coaches both for D.C. and A.C. systems. Control and electric braking circuits are explained with the help of simplified diagrams based on the latest practice in Great Britain and abroad. Chapters are included on the development of single-phase traction at 50 cycles, the electrical equipment of diesel-electric locomotives, and on the operation of high-speed services as exemplified by the Paris-Lyons main-line electrification of the French National Railways

THE DESIGN OF SMALL SINGLE LAYER COILS

By A. I. Forbes Simpson (Radio Works).

Extracted from Electronic Engineering (November 1947) in Radio Designers' Handbook (4th edition, pp. 466-473) by F. Langford Smith.

A family of curves and nomographs correlates the prediction of Magnification Constant (Q) and the direct determination of winding information for coils of low self capacity on commonly used diameters of formers. Presentation in logarithmic form gives a constant reading accuracy and eases extrapolation.

One nomograph shows the effect of screening, and examples of use are given.

A SURVEY OF PRESENT KNOWLEDGE OF THERMIONIC EMITTERS (515)*

By D. A. Wright (Research Staff of The M.O. Valve Co., Ltd. at the G.E.C. Research Laboratories).

Proc. I.E.E. Vol. 100, Part III, No. 65, May, 1953

After an account of factors influencing the work function of metals, values are quoted and the usefulness of a number of metals as practical thermionic emitters is discussed. The effect of adsorbed films is described and illustrated in connection with emitters with monatomic layers of thorium, caesium and barium.

The emission from compounds, and in particular from semi-conductors, is considered, also the behaviour of certain metallic borides and carbides. Some of these, such as lanthanum boride and thorium carbide, are likely to be valuable as practical emitters. The general properties of oxides are discussed and the groups in the periodic table are compared. The barium-strontium-oxide type of cathode is treated separately because it is the most important practical cathode, and the behaviour and limitations are dealt with in some detail. A final section describes the performance of thoria as a thermionic emitter.

NEW EQUIPMENT FOR IMPEDANCE MATCHING AND MEASUREMENT AT VERY HIGH FREQUENCIES (519)*

By A. Bloch, Dr. Ing., M.Sc., F. J. Fisher, M.A., M.Sc., and G. J. Hunt (G.E.C. Research Laboratories).

The slotted transmission line has long been used as a standard device for determining impedance. Over the V.H.F. range, however, the constructional difficulties due to the physical length required for the slotted line make it primarily a laboratory instrument. The need for an alternative device of comparable or improved accuracy, capable of giving much more rapid measurements, and sufficiently robust to be used on field tests of aerial arrays, has led to a modified approach.

A test section of low-loss coaxial line, which may be as short as one-third of the equivalent slotted line, is fitted with fixed probes to measure the relative voltage amplitudes at three known points. From these ratios the unknown impedance can be found, either analytically or graphically, each ratio defining a circular locus on the Smith chart. The frequency range covered by a line of this type is approximately 3 : 1 ; near mid-frequency the present equipment can measure standing-wave ratios up to 5 : 1, corresponding to resistive loads ranging from 15 to 375 ohms. for a line of 75 ohms. An important advantage of the new equipment is that the adjustment of a load to a prescribed value is shown by the simultaneous zero reading of two meters.

CRYSTAL STRUCTURE AND ANTIFERROMAGNETISM OF CrSb (536).*

By B. T. M. Willis (G.E.C. Research Laboratories).

Acta Crystallographica, Vol. 6, Part 5, pp. 425-426. May, 1953

This investigation is concerned with the behaviour of the structure cell of the antiferromagnetic compound CrSb. Like MnTe, the subject of a recent study by Greenwald, this crystallises in the hexagonal system, and possesses the NiAs-type of crystal structure. The investigation has shown that the changes in the structure cell of CrSb in the neighbourhood of its transition point are those to be expected.

A HIGH-TEMPERATURE HIGH VACUUM FURNACE FOR EXPERIMENTAL WORK (524).*

By H. D. Blakelock, B.Sc., and C. F. Machin, B.Sc., F.Inst.P.

The Engineer, July 17th, 1953, p. 83.

The heating element in the furnace described here is a slotted cylinder of graphite suitable for a three-phase supply. The three electrical lead-in connections also serve as mechanical supports for the heating element. For a working temperature of 2,000 deg. C., the furnace loading is less than 6 kW.

*** A limited number of reprints is available of those papers marked with an asterisk. Copies may be obtained on application to the Editor, G.E.C. Journal, Magnet House, Kingsway, W.C.2.**